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ANALYSIS OF EFFECTIVENESS AND COSTS OF RETROFIT EMISSION CONTROL SYSTEMS FOR USED MOTOR VEHICLES. VOLUME III. PERFORMANCE ANALYSIS

Olson Laboratories
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ANALYSIS OF EFFECTIVENESS AND COSTS of RETROFIT EMISSION CONTROL SYSTEMS for USED MOTOR VEHICLES

volume III

performance analysis

prepared under
EPA Contract 68-04-0038

by
Olson Laboratories, Inc.
500 East Orangethorpe Avenue
Anaheim, California 92801

In Association With Northrop Corporation

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for

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Division of Emission Control Technology
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Ann Arbor, Michigan 48105

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D. D. Foulds
Vice President
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NOTICE

This report was prepared for the United States Environmental Protection Agency by Olson Laboratories, Inc. pursuant to an Environmental Protection Agency contract to evaluate automotive emission control retrofit methods. The information presented in this report in no way represents any endorsement or warranty by either the contractor or the United States government of any specific device reported on; nor does it represent any conclusion about the merits of any specific device which was not evaluated. The report is based on the contractor's evaluation of laboratory data developed under the contract, retrofit developer supplied data, and government furnished data when available. The information furnished herein is believed accurate and current as of May 1972.

FOREWORD

The Environmental Protection Agency, as Administrator of the Clean Air Amendments Act of 1970, is required to assist States and air pollution control agencies in meeting national ambient air quality standards and mobile or stationary source emission standards, by issuing information on control techniques. Contract 68-04-0038 was performed with the Office of Air Programs, Division of Emission Control Technology, to determine what emission control techniques are feasible for retrofit to used cars, considering emission reduction effectiveness, costs, effect on vehicle performance, and the facilities and labor skills required for retrofit device installation and eventual maintenance and inspection. This report documents the results obtained, the pertinent data upon which the results are based, the techniques of test and analysis, and the recommendations for future programs to implement the results. The report consists of the following six volumes:

I. Program Summary: Highlights the principal program results and conclusions as to the overall feasibility of retrofit methods for vehicle emission control. Provides guidelines for the evaluation of retrofit approaches and the implementation of control programs.

II. System Descriptions: Documents the physical, functional, and performance characteristics of the candidate retrofit methods and their installation requirements and costs.

III. Performance Analysis: Documents the relative effectiveness and costs of retrofit methods, the techniques of analysis and testing, and the assumptions and rationale upon which the analysis was based.

IV. Test and Analytical Procedures: Documents the approach to the overall program objectives and the tasks and procedures implemented to meet the objectives.

V. Appendices: Documents the raw data obtained from retrofit development sources and data of overall applicability to the report.

VI. Addendum for Durability Tests: Documents the results of 25,000-mile durability tests on four representative retrofit devices.

ACKNOWLEDGMENTS

This program was conducted under the direction and with the assistance of Dr. Jose L. Bascunana, Project Officer of the Environmental Protection Agency. Emission Control Technology, Inc., provided the methodology for performance analysis under a subcontract agreement with Olson Laboratories, Inc.

The accomplishment of this program was made possible by the cooperation and assistance of the many developers and manufacturers of retrofit devices. Their contribution of coordination time, data, and retrofit device hardware is very much appreciated.

GLOSSARY

AMA	Automobile Manufacturers Association
CEI	Cost Effectiveness Index
CI	Cost Index
CID	Cubic inch displacement
CNG	Compressed natural gas
CO	Carbon monoxide
CVS	Constant volume sampling
DI	Driveability Index
EGR	Exhaust gas recirculation
EI	Emission Index
EPA	Environmental Protection Agency
gm/mi	Grams per mile
HC	Hydrocarbons
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MMBM	Mean-miles-before-maintenance
MMBPF	Mean-miles-before-partial-failure
MMBTF	Mean-miles-before-total-failure
mph	Miles per hour
mpg	Miles per gallon
MTTM	Mean-time-to-maintain
MTTR	Mean-time-to-repair
NDIR	Nondispersive infrared
NOx	Oxides of nitrogen
OEM	Original equipment
PCV	Positive crankcase ventilation
PI	Performance Index
ppm	Parts per million
SAE	Society of Automotive Engineers
WOT	Wide open throttle

TABLE OF CONTENTS

Section			Page
	FOREWORD		iii
	ACKNOWLEDGMENTS		v
	GLOSSARY		vi
1	INTRODUCTION		1-1
	1.1	Evaluation Objectives	1-1
	1.2	Evaluation Approach	1-2
	1.3	Evaluation Conclusions	1-2
2	RETROFIT METHOD APPLICABILITY TO USED CAR EMISSION CONTROL		2-1
	2.1	The Impact of Retrofit Controls on Used Vehicles	2-1
	2.2	Retrofit System Emission Control Capability	2-2
3	EVALUATION METHODOLOGY		3-1
	3.1	CRITERIA INDEX	3-2
	3.1.1	Emission Standards Factor	3-4
	3.1.2	Emission Baseline Factor	3-4
	3.1.3	Safety Factor	3-4
	3.1.4	Critical Driveability Factor	3-5
	3.1.5	General Driveability Factor	3-5
	3.1.6	Installation Cost Factor	3-6
	3.1.7	Recurring Cost Factor	3-6
	3.1.8	Reliability Factor	3-6
	3.1.9	Maintainability Factor	3-6
	3.1.10	Availability Factor	3-7
	3.2	Performance Index	3-7
	3.2.1	Emission Index	3-8
	3.2.2	Driveability Index	3-9
	3.2.3	Cost Index	3-10
	3.3	Cost Effectiveness Index	3-12
	3.4	Establishing Weighting Coefficients for the Performance Index	3-12
4	RETROFIT PERFORMANCE ANALYSIS		4-1
	4.1	Engineering Analysis	4-1
	4.1.1	Engineering Analysis Team	4-1
	4.1.2	Engineering Analysis Approach	4-2
	4.2	Test Program	4-4
	4.2.1	Test Vehicle Fleet	4-4
	4.2.2	Selection of Retrofit Test Devices	4-8
	4.2.3	Test Approach	4-8
	4.2.4	Test Procedures	4-12
	4.3	Performance Analysis Data Inputs and Results	4-13

CONTENTS (CONTINUED)

Section			Page
5	CRITERIA INDEX ANALYSIS		5-1
	5.1	Evaluation Criteria	5-1
	5.2	Criteria Index Results	5-1
	5.3	Retrofit System Feasibility	5-5
6	PERFORMANCE INDEX ANALYSIS		6-1
	6.1	Emission Reduction Results	6-1
	6.1.1	Device 1: Air Bleed to Intake Manifold	6-8
	6.1.2	Device 96: Catalytic Converter with Vacuum Advance Disconnect	6-9
	6.1.3	Device 175: Ignition Timing Modification with Lean Idle Adjustment	6-11
	6.1.4	Device 246: Exhaust Gas Recirculation with Vacuum Advance Disconnect	6-11
	6.1.5	Emission Reduction Versus Engine Size	6-12
	6.1.6	Emission Index Results	6-12
	6.2	Driveability Index	6-12
	6.2.1	Driveability Index Results	6-15
	6.2.2	Driveability Index Sensitivity Analysis	6-18
	6.3	Cost Index	6-18
	6.3.1	Initial Costs	6-19
	6.3.2	Recurring Costs	6-19
	6.3.3	Cost Index Results	6-20
	6.3.4	Cost Index Sensitivity Analysis	6-22
	6.4	Performance Index	6-23
	6.4.1	Performance Index Results	6-24
	6.4.2	Weighting Coefficient Sensitivity Analysis	6-24
7	COST EFFECTIVENESS INDEX		7-1
8	GUIDELINES FOR SELECTING AND IMPLEMENTING RETROFIT METHODS		8-1
	8.1	Defining the Required Emission Reduction	8-2
	8.2	Defining the Uncontrolled Vehicle Population	8-2
	8.3	Identifying Candidate Retrofit Methods	8-3
	8.4	Determining Cost Effective Retrofit Methods	8-5
	8.5	Defining the Certification Program	8-7
	8.6	Cost Effectiveness Studies of Alternative Control Programs	8-8
	8.7	Preparing an Implementation Plan	8-8
	8.8	Implementing the Plan	8-9
9	RECOMMENDATIONS		9-1
10	REFERENCES		10-1

CONTENTS (CONTINUED)

Appendix | Page

A Baseline Exhaust Emissions for Test Vehicles Prior to Each Retrofit Test (1972 Federal Test Procedure Grams/Mile) . . . A-1

B-1 Retrofit Program Test Schedule B-1

B-2 Retrofit Program Test Summary Versus Contract Requirements . . B-1

C Devices Evaluated in Retrofit Program C-1

D Performance Analysis Input Data D-1

E Computer Analysis Results. E-1

F Baseline and Retrofit Emission Levels in Grams/Mile for Devices Tested in Retrofit Program by 1972 Federal Test Procedure F-1

G Mean Emission Levels for Retrofit Devices Evaluated Based on EPA and Retrofit Developer Test Data G-1

H Welch's Approximate t Solution of the Fisher-Behrens Problem . H-1

J Sensitivity Analysis of Retrofit Program Driveability and Cost Indexes J-1

K Cost Index Results for Retrofit Devices with Cost Data K-1

L Fuel Consumption Measured During the 1972 Test for Devices Tested in the Retrofit Program L-1

ILLUSTRATIONS

Figure | Page

2-1 Sources and Quantities of Emissions from an Uncontrolled Vehicle 2-3

4-1 Baseline and Retrofit System Test Sequence for Each Test Vehicle 4-11

6-1 Mean Percentage Emission Reduction and 90 Percent Confidence Limits for Exhaust Emission Control Retrofit Systems Tested at Anaheim, California, and Taylor, Michigan 6-10

8-1 Typical Example of Program Management Structure for Periodic Vehicle Inspection Program 8-10

TABLES

Table Page

2-1 Estimated Percentage of Vehicle Population that Could be Retrofitted with Emission Control Systems. 2-3
2-2 Potential Pollutant Control Capability of Retrofit Methods by Generic Groups 2-5
3-1 Performance Parameters and Evaluation Criteria 3-3
3-2 Weighting Coefficients for the Performance Index 3-14
4-1 Test Vehicle Fleet 4-5
4-2 Test Fleet Exhaust Emissions 4-6
4-3 Taylor vs Anaheim Test Vehicle Baseline Emission Level Differences in Mean Grams/Mile (Based on Appendix A) 4-9
4-4 Retrofit Devices Selected for Test Program 4-10
5-1 Criteria Index Results for Devices Evaluated in Retrofit Program . 5-2
6-1 Percentage Emission Reduction of Devices Tested in Retrofit Program. 6-3
6-2 Average Percentage Exhaust Emission Reduction by Test Procedure for Devices Evaluated in Retrofit Program. 6-6
6-3 Discriminatory Power of t Tests. 6-8
6-4 Mean Percentage Emission Reduction and 90 Percent Confidence Intervals for Exhaust Emission Control Retrofit Systems Tested at Anaheim, California and Taylor, Michigan 6-9
6-5 Rank Ordered Emission Index Values by Test Method for Retrofit Devices Evaluated. 6-13
6-6 Weighting Factors Used for General Driveability Index Calculations 6-15
6-7 Driveability Index Results in Rank Order for Devices Tested in Retrofit Program 6-16
6-8 Sensitivity Analysis Calculation for the Driveability Index . . . 6-18
6-9 Average Fuel Mileage Change for Exhaust Emission Control Retrofit Systems Tested at Anaheim, California, and Taylor, Michigan 6-20
6-10 Cost Index in Order of Rank for Retrofit Devices with Cost Data . 6-21
6-11 Cost Index Sensitivity Analysis Results 6-23
6-12 Mean Performance Index Results in Rank Order for Devices Tested in Retrofit Program 6-25
6-13 Performance Index with Alternate Weighting Coefficients for Devices Tested in Retrofit Program 6-27
7-1 Cost Effectiveness Index in Order of Rank for Retrofit Devices with Cost and Emission Data 7-3
8-1 Light Duty Vehicle Population and Type of Emission Control 8-4
8-2 Performance Parameters and Evaluation Criteria 8-6

SECTION 1

INTRODUCTION

The retrofit study program has enabled an evaluation to be performed as to the relative effectiveness and costs of retrofit methods as a feasible approach to the control of emissions from the used car population. This study was performed on the basis of data obtained through a comprehensive data search and further developed by system engineering analysis and tests of individual retrofit devices. The study was directed toward specific objectives which are all concerned with answering several fundamental questions:

a. Is the retrofit approach a feasible technique for used car emission control?

b. What retrofit devices are feasible for implementation of the retrofit control technique?

c. What are the recommended future research and development programs, and the guidelines for implementing the retrofit approach?

To answer these questions a system analysis and test program was performed on 65 devices covering the range of possible retrofit approaches. These analyses and tests were performed to develop the objective data required to evaluate the principal performance parameters, effectiveness, and costs of retrofit devices. These data were then analyzed by means of a mathematical model specifically designed to evaluate each retrofit device according to its performance.

1.1 EVALUATION OBJECTIVES

The specific retrofit evaluation objectives were to:

a. Determine the relative effectiveness of each retrofit device for controlling HC, CO, and NOx emissions as compared to an uncontrolled used car.

b. Determine the effect of emission reduction effectiveness on the driving characteristics of the cars and on costs to the vehicle owner, considering that emission reduction has to be achieved within the constraints of vehicle performance requirements for driveability, reliability, maintainability, and safety, and be within an acceptable cost limit.

c. Determine the relative effectiveness and costs of retrofit devices that are feasible for the used car population. This includes installation and operational costs and the maintenance requirements of retrofit systems.

d. Provide guidelines to assist in retrofit method selection and accreditation by agencies responsible for planning and implementing air quality control strategies.

e. Determine areas of future research and development for uncontrolled vehicle emission control by the retrofit method.

1.2 EVALUATION APPROACH

The initial data were obtained by data survey, as discussed in Volume IV. These data were screened to identify those retrofit devices which were candidates for emissions and driveability testing in order to develop a more comprehensive data base. System engineering analysis was performed on 65 retrofit devices and tests were performed on 11 of these devices. The system engineering analysis results for all devices are reported in Volume II. The evaluation results for the 11 devices tested in the retrofit program are reported in this volume, along with the results for devices evaluated on the basis of developer and EPA data.

1.3 EVALUATION CONCLUSIONS

The feasibility of using retrofit devices for controlling used car emissions requires consideration of both the technical and economic aspects of the retrofit approach. The number one technical consideration is whether these devices can lower used car emissions. Next, but equally important, is whether the lower emissions can be obtained reliably, safely, and with minimum adverse effect on overall vehicle driveability and maintenance. These technical considerations all influence the effectiveness of retrofit devices for used car emission control. With these considerations resolved, the economic considerations must then be examined. These considerations all involve how much the effectiveness in lower emissions costs. These costs are determined by how much a device costs to buy, install, operate, and maintain. If the costs and the effectiveness are reasonable, then a retrofit device can be considered feasible.

The study of retrofit methods documented in this report has indicated that certain exhaust emission control retrofit devices are feasible in terms of this cost effectiveness rationale. The study was concentrated on exhaust emission controls, since blowby controls have been in use on a retrofit basis for a number of years and there were no fuel evaporative control systems found for retrofit use, other than in one combination device (Device 165). The exhaust control systems studied were found to operate on the same basic principles used to control emissions on new cars. These principles, as implemented in the retrofit systems, include:

a. Lean air-fuel mixture, generally by means of air bleed to the intake manifold, to decrease CO and HC by improved oxidation.

b. Retarded ignition timing to inhibit NOx formation by lower combustion temperature and to decrease HC by oxidation in the resultantly hotter exhaust gas.

c. Thermal oxidation of CO and HC in the exhaust system by means of reactors.

d. Use of catalytic converters as an alternative to thermal reactors.

e. Exhaust gas recirculation to inhibit NOx formation by lower combustion temperature.

f. Use of alternative fuels or additives.

g. Combinations of these.

The retrofit study indicated that, except for the air-bleed-to-intake-manifold approach, these principles are usually implemented in retrofit devices in combinations of two or more. Combinations are necessary if all three pollutants are to be controlled. While this approach was found to increase emission reduction effectiveness, in some devices it increased costs undesirably.

The air bleed system tested in the retrofit program was found to provide effective control of CO and, to a lesser extent, HC. The air bleed systems studied ranged in initial cost from about \$23 to \$64. These systems indicate that they may provide a recurring cost savings, due to the reduced fuel consumption resulting from a leaner air-fuel mixture.

The systems tested to evaluate the effectiveness of ignition timing modification and exhaust gas recirculation were effective in reducing NOx. These systems were combined with lean idle mixture and vacuum advance disconnect, respectively, and indicated some reduction of CO and HC as well. Their initial costs were reported by the development sources as \$45 and \$89, respectively. Whereas the timing modification system indicated increased recurring costs due to higher fuel consumption, the exhaust gas recirculation system indicated that fuel consumption could be less with the device installed.

A catalyst system was tested to evaluate the effectiveness of exhaust gas oxidation to control CO and HC. This system indicated the highest overall emission reduction effectiveness, because it incorporated vacuum advance disconnect to control NOx. However, the requirement for an air pump increases the initial cost of this system to approximately \$175. Without the air pump, the initial cost would still be about as high as the EGR system, but the emission reduction effectiveness for CO and HC appears to decrease substantially.

These results indicate the basic effectiveness and cost characteristics of the feasible retrofit methods studied in the retrofit program. Basically, high emission reduction effectiveness was indicated as being accompanied by generally higher costs, both initial and recurring. These costs are mainly attributable to the cost of the device and higher fuel consumption. Reliability, maintenance, safety, and driveability were not indicated as being major problems, though vehicle acceleration may be slightly slower, particularly with retarded ignition timing.

In summary, the principal compromise that use of the retrofit method appears to require is one of effectiveness versus cost. While there are alternative retrofit devices that appear to be feasible, the choice among them depends on the severity of the emission reduction required by air quality control regions.

SECTION 2

RETROFIT METHOD APPLICABILITY TO USED CAR EMISSION CONTROL

The analysis of retrofit methods as a means of controlling vehicle emissions from the used car population must begin by establishing the need for such control. In this section, the applicability of retrofit controls to used cars is reviewed with respect to the pollutant control potential of retrofit methods.

2.1 THE IMPACT OF RETROFIT CONTROLS ON USED VEHICLES

In the contract under which this study was conducted, the Environmental Protection Agency aptly summarized the requirement for a viable automobile emission control retrofit program in the United States:

> "At present, there are nearly 100 million light duty vehicles operating in the United States, with a current manufacturing rate of around 8.5 million new vehicles per year. Of these vehicles, the 1971 year models have control for evaporative, exhaust, and blowby emissions, the 1968 to 1970 models have controls for exhaust and blowby, the 1963 to 1967 models have only control for blowby, and models earlier than 1963 have no emission controls. (Controls were introduced earlier in the State of California, i.e., in 1961, 1966, and 1970, respectively.)
>
> "Considering the large proportion of used to new vehicles, it is evident that a substantial improvement in atmospheric pollution could be achieved if the emissions from used cars were restrained by some means to ensure that the cars manufactured without emission controls emitted less than they normally would." (Reference 1)

Presently, vehicles without exhaust control devices that control HC and CO represent 68 percent of the total U.S. vehicle population and 55 percent of California vehicle population. This is shown in Table 2-1. In 1976, approximately 26 percent of the total U.S. vehicle population will still be without exhaust controls unless a retrofit program is implemented.

As an illustration of the applications that retrofit methods can have in controlling vehicle emission sources, Figure 2-1 shows the primary sources and amounts of emissions from an uncontrolled vehicle. Note that most of the vehicle's emissions are from the exhaust.

2.2 RETROFIT SYSTEM EMISSION CONTROL CAPABILITY

The various concepts for reducing and controlling exhaust emissions from used automobiles fit into the following basic categories:

a. Exhaust Control Systems

b. Crankcase Emission Control Systems

c. Evaporative Emission Control Systems

d. Emission Control Combinations

Table 2-2 lists the generic group classifications of the various types of retrofit control systems studied. The pollutants that these devices are designed to control are also listed. Each type of system has the potential for controlling one or more of the pollutants for which control is required.

The detailed principles of retrofit device operation are presented in Volume II. In general, the exhaust gas control systems are designed to control hydrocarbons and carbon monoxide. Some catalytic systems are designed for control of the oxides of nitrogen as well as HC and CO. The exhaust gas filter is primarily for particulate emission control from the vehicle's tailpipe.

The induction control systems, except for exhaust gas recirculation, generally are designed to decrease HC and CO emission levels. The bleeding of air to the intake manifold is based on leaning the carburetor air-fuel ratio and improving fuel distribution, to decrease CO and HC. The exhaust gas recirculation (EGR) systems are primarily designed to lower the oxides of nitrogen (NOx) by decreasing combustion temperature. Variable camshaft timing is a form of exhaust gas recirculation in which the valve timing is changed over the speed range of the engine. Intake manifold modifications are designed to improve fuel distribution to the cylinders for more complete combustion and reduced emissions. Carburetor modifications generally involve the idle or main circuits and sometimes consist of entire carburetor replacement with the objective of improving fuel distribution or air-fuel ratio for lower CO and HC emissions.

Ignition control systems modify the ignition advance curves or the duration of spark plug firing time. These systems generally are intended to lower combustion temperatures and inhibit NOx formation, and also to promote HC oxidation in the exhaust. The ignition advance mechanisms generally retard the total advance by disconnecting the distributor vacuum advance unit. Some devices modify the distributor advance characteristics electronically.

Fuel modification systems alter the normal combustion process by use of different fuels or by adding a fuel additive to the fuel. The gaseous fuel conversion systems are designed to lower emission levels and prolong engine life by use of lower reactivity fuels and special tuning. Fuel additives are intended to clean up carburetor and engine deposits with mileage accumulation and to keep deposit levels low when the engine and carburetor systems are new; also, these additives frequently are claimed to improve combustion and thereby lower emissions.

Table 2-1. ESTIMATED PERCENTAGE OF VEHICLE POPULATION THAT COULD BE RETROFITTED WITH EMISSION CONTROL SYSTEMS (REFERENCE 2)

CALIFORNIA				REST OF UNITED STATES		
YEAR	BLOWBY	EXHAUST	EVAP	BLOWBY	EXHAUST	EVAP
1971	1%	55%	92%	26%	68%	91%
1972	1	45	83	20	58	79
1973	1	37	74	15	49	68
1974	1	31	64	11	40	58
1975	1	24	55	8	33	49
1976	0	19	45	5	26	40
1977	0	15	37	4	20	33
1978	0	12	31	3	15	26
1979	0	9	24	2	11	20
1980	0	6	19	1	8	15
1981	0	4	15	0	5	11

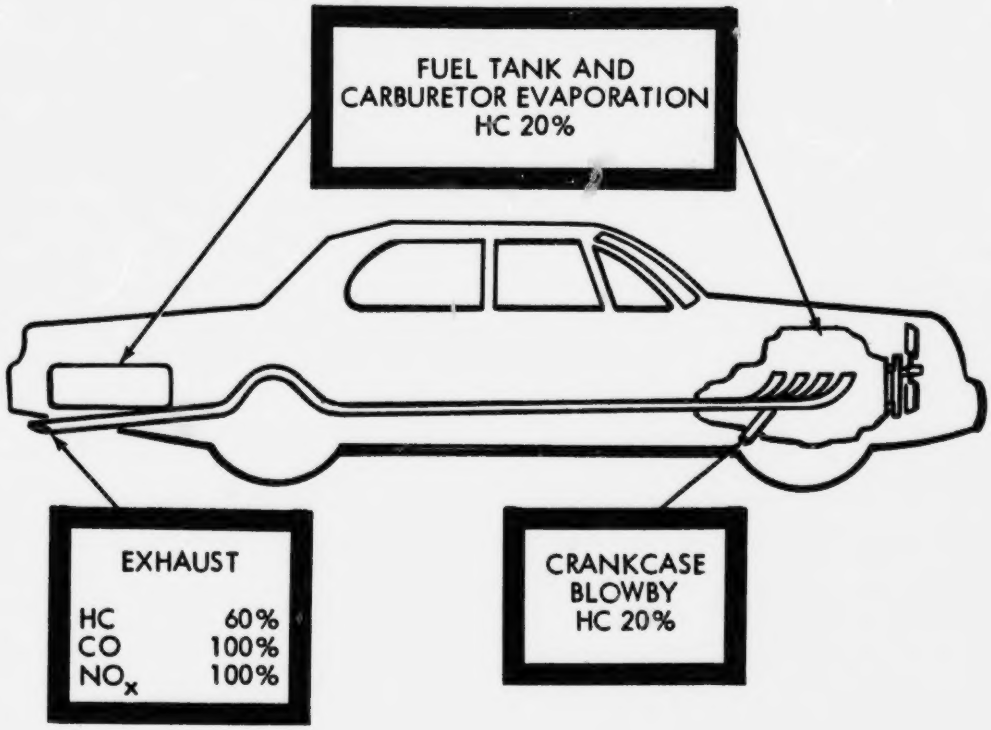

FUEL TANK AND
CARBURETOR EVAPORATION
HC 20%
EXHAUST
HC 60%
CO 100%
NO$_x$ 100%
CRANKCASE
BLOWBY
HC 20%

Figure 2-1. SOURCES AND QUANTITIES OF EMISSIONS FROM AN UNCONTROLLED VEHICLE (REFERENCE 3)

Crankcase emission control systems recirculate the blowby gases to the engine's induction system. Blowby gases are mostly an air-hydrocarbon mixture which leaks past the piston rings during the compression stroke. Recirculating blowby gases to the induction system recovers approximately 20 percent of the total vehicle HC emissions that would have otherwise been emitted to the atmosphere from an uncontrolled car (refer to Figure 2-1).

Evaporative emission control systems prevent hydrocarbon emissions into the atmosphere from the vehicle's fuel tank and carburetor bowl vents. Fuel evaporative emission control systems recover approximately 20 percent of the hydrocarbons that would be emitted to the atmosphere from cars not equipped with emission controls.

The combination control group consists of those retrofit systems which combine the emission control approaches of two or more generic groups. Some of these systems have potential for controlling HC, CO, and NOx exhaust emissions.

Table 2-2. POTENTIAL POLLUTANT CONTROL CAPABILITY OF RETROFIT METHODS BY GENERIC GROUPS

GROUP	TYPE	SUB-TYPE	TITLE	POLLUTANTS CONTROLLED HC	CO	NOx	PARTICULATES
1			Exhaust Emission Control Systems				
	1.1		Exhaust Gas Control Systems				
		1.1.1	Catalytic Reactor	x	x	x	
		1.1.2	Thermal Reactor	x	x		
		1.1.3	Exhaust Gas Afterburner	x	x		
		1.1.4	Exhaust Gas Filter				x
		1.1.5	Exhaust Gas Backpressure	(Not Established)			
	1.2		Induction Control Systems				
		1.2.1	Air Bleed to Intake Manifold	x	x		
		1.2.2	Exhaust Gas Recirculation			x	
		1.2.3	Intake Manifold Modification	x	x		
		1.2.4	Carburetor Modification	x	x		
		1.2.5	Turbocharger	x	x		
		1.2.6	Fuel Injection	x	x		
	1.3		Ignition Control Systems				
		1.3.1	Ignition Timing Modification	x		x	
		1.3.2	Ignition Spark Modification	x			
	1.4		Fuel Modification				
		1.4.1	Alternative Fuel Conversion	x	x		
		1.4.2	Fuel Additive	x	x		
		1.4.3	Fuel Conditioner	x	x		
2			Crankcase Emission Control Systems				
	2.1		Closed Systems	x			
	2.2		Open Systems	x			
3			Evaporative Emission Control Systems				
	3.1		Crankcase Storage	x			
	3.2		Canister Storage	x			
4			Emission Control Combinations (1)	x	x	x	x

(1) Combinations of Groups 1, 2, and 3

SECTION 3

EVALUATION METHODOLOGY

One of the principal objectives of the retrofit study was to compare the overall emission reduction performance and costs of the various retrofit devices relative to each other. Three quantitative indexes were developed for each device, to provide a numeric rating by which to compare the devices. These indexes were identified as the criteria, performance, and cost effectiveness indexes. The indexes were developed as part of a uniform evaluation methodology for vehicular emission control systems.

To analyze a retrofit device for its effectiveness and costs in reducing vehicle emissions, and then to compare that device with others to determine its relative effectiveness and cost, requires a carefully formulated method of analysis which can be applied uniformly to each device. The concept of this methodology must be based on such fundamentals as:

a. What do the terms "effectiveness" and "costs" mean, and

b. What specific questions about these terms is the analysis to answer.

The "effectiveness" of a retrofit device refers to how well it performs its intended function. The "costs" are the monies paid for that performance. For analytical purposes, quantitative measures must be defined for these terms.

The effectiveness of a retrofit device is measurable by its ability to reduce vehicle emissions without adversely affecting vehicle driveability and safety. The costs of a device are measurable by its retail and installation price plus the expense of operating and maintaining the device during its useful life.

To organize these parameters into a logical and orderly evaluation methodology, it was necessary to define specifically what basic questions the analysis was to answer. These basic questions provided the objectives or constraints which the methodology was structured to meet and were arranged in order of priority and quantified in terms of emissions reduction, driveability impact, and cost impact. The questions asked:

a. To what extent does the device reduce the vehicle's objectionable emissions, and could such reduction pass legislated standards? (Quantitatively identified as the Emission Index.)

b. Does the device cause any adverse side effects in vehicle safety and driveability? (Quantitatively identified as the Driveability Index.)

c. How much money does the emission reduction device cost the vehicle owner, in terms of dollars per mile of vehicle driving and inconvenience due to having his vehicle in the garage for servicing and repair? (Quantitatively identified as the Cost Index.)

To perform a complete system analysis of each device, evaluation criteria for these three indexes of performance were defined. In this project, the particular criteria values shown in Table 3-1 were used. Each factor of Table 3-1 represents an input to the applicable index of a device's performance. These performance parameters and evaluation criteria were selected for the retrofit program by a Technical Review Board (described in Volume IV). Most of the criteria were selected from the California used car certification requirements and procedures (References 12 and 16) because no other used car criteria were available for consideration. Governmental air pollution agencies responsible for certifying retrofit systems may use this set of criteria or select alternate criteria to fit their specific vehicle emission abatement goals.

The summation of the Emission, Driveability, and Cost Indexes was defined as the Performance Index. The quantitative results obtained from this calculation for each device can be uniformly compared and evaluated to determine the relative performance of devices in terms of these three indexes.

In addition to the quantitative Performance Index (PI), a qualitative index was developed as a caution flag to indicate when certain criteria need closer scrutiny. This index was called the Criteria Index.

Finally, the Cost Effectiveness Index (CEI) was developed to distinguish between high cost devices and high emission reduction effectiveness and low cost devices and low emissions reduction effectiveness without regard to driveability considerations. The CEI determines how much emission reduction benefit is obtained considering the initial cost, maintenance, and operating cost for each mile of vehicle operation.

3.1 CRITERIA INDEX

The Criteria Index provides a gross feasibility evaluation of each device, and a quick indication as to whether a device meets the various legislated constraints or limits specified for each performance parameter. The Criteria Index is a product of terms, each having values of either one or zero. If the result of this product is equal to one, it means the device has met the legal and implicit requirements for all the criteria or standards specified. If the result is zero, it means the device did not pass one or more of the individual criteria or standards. The device is then flagged as being substandard for a given set of evaluation criteria. The criteria limits may remain flexible to allow for criteria changes due to differences in State or regional requirements.

The Criteria Index is made up of 10 factors:

1. Emission standards

2. Emission baseline

3. Safety

Table 3-1. PERFORMANCE PARAMETERS AND EVALUATION CRITERIA

FACTOR	CRITERIA
1. **Emission Index Factors**	
a. Emission standards (1)	
HC	Less than 350 ppm or 4.5 gm/mi
CO	Less than 2.0% or 47.6 gm/mi
NOx	Less than 800 ppm or 3.0 gm/mi
b. Emission baseline	No increase of any pollutant beyond an allowable experimental error (2)
2. Driveability and Safety Index Factors	
a. Safety	No hazardous conditions
b. Critical driveability	No stall on acceleration No hot idle stall No backfire
c. General driveability	Driveability Index less than 1.0 (refer to para. 3.1.5)
3. Cost and Cost-Related Index Factors	
a. Installation cost (including kit)	Less than $85.00, including labor at $12.50 per hour (3)
b. Recurring cost	Less than $15.00 per year ($0.125 per 100 miles) (4)
c. Reliability	At least 50,000 miles of operation before total failure
d. Maintainability	At least 12,000 miles of operation before periodic maintenance is required
e. Availability	Less than 1 repair hour per 12,000 miles of operation (4)

(1) The volume concentration values are the California used car device accreditation standards as specified in California Health and Safety Code Chapter 4, Article 2, paragraph 39107 (refer to Volume IV, Appendix E). These standards are for the 7-mode cold-start test cycle specified in the 1970 Federal Test Procedure (see pertinent comments and cautions in paragraph 5.1 of this volume). The grams per mile (gm/mi) correlated with the above standards were calculated for a 4,000-pound vehicle in accordance with the method set forth in the 1970 Federal Test Procedure. If the evaluator intends to use the 1972 Federal CVS Test Procedure, appropriate used car standards must be established for that test procedure.

(2) In this report, an experimental error of +10% was used.

(3) $12.50 per hour based on California repair labor average.

(4) Average miles driven per year assumed to be 12,000 miles.

4. Critical driveability
5. General driveability
6. Installation cost
7. Recurring cost
8. Reliability
9. Maintainability
10. Availability

The criteria used for each of these factors in the analysis performed during this study are presented in Table 3-1. Caution must be used in applying these criteria to other situations. They are presented here only to demonstrate the analytical procedures for retrofit analysis. These criteria, however, are based on actual requirements and guidelines used by the State of California in accrediting used car exhaust emission control devices (References 12 and 16).

3.1.1 Emission Standards Factor

The States or air quality regions requiring vehicle emission control would set emission level standards that must be met for a retrofit device to be accredited for use. To evaluate a device against these standards, the device would be installed on a vehicle not already equipped with a similar pollution control system.

If the device demonstrates emission levels equal to or below the standard levels, such as those listed in Table 3-1, the device receives a rating of one. If the emission standards are exceeded, the rating is zero.

3.1.2 Emission Baseline Factor

The basic purpose of a retrofit system, obviously, is to reduce emissions, not to increase them. The emission baseline factor prohibits HC, CO, and NOx pollutant level increase from baseline levels with the device installed. Before the emission baseline factor is set equal to zero, an experimental error is allowed due to variations in test repeatability, and a small increase (10 percent was used in this study) is allowed. This allowable increase is dependent upon the testing facility equipment and procedures.

In some cases a retrofit device may be designed to specifically control only one pollutant. In these cases, the criterion would not allow an increase in emission levels from baseline levels of the uncontrolled pollutant.

3.1.3 Safety Factor

The safety factor is determined by an engineering evaluation and driveability testing of each device. Any potential dangers are identified with respect to design, installation, or modes of operation. The hazardous conditions for which a retrofit device may affect vehicle operation and human safety include:

a. Any exhaust gas leakage, porting, or venting that could be hazardous to persons in or near a vehicle.

b. Spillage or leakage of raw fuel near a source of ignition that could result in a fire hazard.

c. Engine failure or loss of power that could result in hazardous driving conditions.

d. Excessive device or engine temperatures that could degrade vehicle reliability, maintainability, driveability, or present a fire hazard.

Any device that possesses any of these safety hazards is given a rating of zero. If none of these hazards are expected to exist, the safety index for a device is rated one.

3.1.4 Critical Driveability Factor

There are five driveability test parameters which are considered to be critical. These parameters, if they exist, have an adverse effect on the safety and, therefore, the acceptability of the device being evaluated. These parameters are:

a. Stall on acceleration and backfire during the cold start drive-away test, and

b. Stall at idle, stall on acceleration, and backfire during the hot start drive-away test.

Stall on acceleration could be the cause of a vehicle accident in heavy freeway traffic. The backfire conditions are potential fire hazards. Stall at hot idle might occur and provide a hazardous situation such as stalling in the middle of an intersection. In addition, a stalled vehicle invites aggravation of the driver and the drivers of vehicles behind the stalled vehicle. Should any of these five conditions exist, over and above those that might exist for the baseline vehicle, the device is given a critical driveability rating of zero. Otherwise the critical driveability rating is one.

3.1.5 General Driveability Factor

The general driveability factor is determined from the value of the Driveability Index (DI) as defined further in paragraph 3.2.2. If the DI exceeds the assumed criterion of one, the device receives a general driveability factor rating of zero. The criterion of 1.0 was arrived at by calculating the DI using the following assumed maximum acceptable driveability parameter degradations:

a. Two-second degradation in cold and hot start times

b. A trace of rough idle when engine is cold

c. A trace of surge and stretchiness when engine is hot.

d. One and a half seconds average acceleration loss (2.0 seconds for large V-8's, 1.5 seconds for small V-8's, 1.0 second for four- and six-cylinder cars).

If the DI is less than or equal to the criterion value, a rating of one is assigned.

3.1.6 Installation Cost Factor

The installation cost of the retrofit device is determined by the retail cost of the device kit, including installation costs (time multiplied by the labor rate, which was assumed to be $12.50 per hour) and the cost of any required adapters. An installation cost factor of one is assigned when this sum is less than or equal to the evaluation criterion ($85.00). Should the criterion value be exceeded, the rating is zero.

3.1.7 Recurring Cost Factor

The recurring cost of the device takes into account all of those incremental costs due only to the continued operation of the retrofit device. It includes the cost of periodic maintenance of the device, repairs for failed parts, total replacement if required, and any incremental losses in fuel economy. The recurring cost is obtained from the Cost Index (CI), as defined further in paragraph 3.2.3. The units used for the CI are dollars per mile, while the assumed criterion value for recurring cost is given in dollars per year. The conversion is accomplished by dividing the dollars per year value by 12,000 miles driven per year. When the device recurring costs exceed the criterion value of $0.125/100 miles, the recurring cost factor is given a value of zero. Otherwise the factor value is one.

3.1.8 Reliability Factor

The reliability of a device may be defined as the accrued vehicle mileage before a component of the retrofit system fails, requiring repair; or the accrued mileage before the total retrofit system fails, requiring complete replacement. These factors are expressed as mean-miles-before-partial-failure (MMBPF) of a device and mean-miles-before-total-failure (MMBTF), respectively. A detailed analysis of each device component for failure characteristics, longevity, and costs was not within the scope of this study. However, a limited reliability engineering analysis was conducted on each device as described in Volume II. The results of this limited analysis provided a mileage value representing the mean miles before system failure, which, in most cases, was for total system failure. When this value is less than the minimum reliability allowed by the reliability criterion (50,000 miles), the reliability factor is set equal to zero. If the device is capable of operating longer than 50,000 miles, the reliability factor is one.

3.1.9 Maintainability Factor

Maintainability, as used here, refers to the need for periodic maintenance as a result of installing a retrofit device. It is expressed in terms of mean-miles-before-maintenance (MMBM). For the minimum criterion of 12,000 miles established in the retrofit study, a one is assigned to the maintainability factor if this minimum criterion is surpassed, and a zero is assigned if the device requires periodic scheduled maintenance more often than 12,000 miles.

3.1.10 Availability Factor

The availability factor reflects the time inconvenience to the car owner due to device maintenance or repair time and cost. This factor is the ratio of the total miles of service life before device failure to the total hours for failure repair and periodic maintenance of the device. The value for this factor is given by the following equation:

$$\text{Availability, } A = \frac{\text{MMBPF}}{\text{MTTR} + \left(\frac{\text{MMBPF}}{\text{MMBM}}\right)\text{MTTM}}, \text{ miles/repair and maintenance hour} \qquad (3.1)$$

Where: MMBPF = Mean-miles-before-partial-failure
MMBM = Mean-miles-before-maintenance
MTTR = Mean-time-to-repair, hours
MTTM = Mean-time-to-maintain, hours

The availability factor is set equal to one when the availability is greater than the criterion (12,000 miles per repair and maintenance hour). If the availability is less than 12,000 miles per repair and maintenance hour, it receives a zero.

3.2 PERFORMANCE INDEX

The Performance Index (PI) is represented by a summation equation designed to obtain a quantitative rating of the devices under evaluation. This equation measures the relative performance ratings of the devices, and allows evaluation even if they do not pass State or regional Criteria Index requirements.

While the Criteria Index equation described in paragraph 3.1 screens the devices for a "yes" or "no" answer as to their gross feasibility, the PI answers the question, "how feasible?" The Performance Index is quantified by subtracting the general Driveability Index and the Cost Index from the Emission Index. This subtraction shows whether the emission reduction benefit of a device is greater than its cost and driveability penalties; and how much greater the benefit is.

The PI equation is comprised of three subindexes, each corresponding to a different performance characteristic. The first is the Emission Index. It has no dimension, since it is expressed as per unit of reduction from baseline emission level. The second is the Driveability Index, in which the ratings are based on the results of driveability tests. The third index is the Cost Index, which carries the units of dollars per 100 miles.

In order to add these individual indexes together realistically, weighting coefficients (C_i) must be assigned. These coefficients are used to reflect the evaluator's choice as to the relative degree of importance to be given each index.

The general form of the Performance Index (PI) is given by the following equation:

$$PI = \frac{C_1 \begin{pmatrix}\text{Emission Index, Per}\\ \text{Unit of Reduction}\end{pmatrix} - C_2 \begin{pmatrix}\text{Driveability}\\ \text{Index, Points}\end{pmatrix} - C_3 \begin{pmatrix}\text{Cost Index,}\\ \text{\$/100 Miles}\end{pmatrix}}{C_1 + C_2 + C_3} \qquad (3.2)$$

The negative signs are used so as to subtract driveability and cost penalties from the emission reduction benefits provided by a device. Thus a positive PI means that the emission reduction capability of a device is greater than its vehicle driveability and cost penalties. By careful and orderly examination of the quantified parameters of each index and of the combined mathematical expressions of these indexes, the relative merits of the various emission control devices for retrofit application may be objectively compared and graded.

The mathematical expressions used in this analysis are developed below for the Emission, Driveability and Cost Indexes. Scaling factors (S_i) are incorporated so that different magnitude indexes can be related.

3.2.1 Emission Index

This index provides the per unit reduction of vehicle emission reduction, with the retrofit device installed, from the baseline emission level of the vehicle without the device installed. This per unit reduction is expressed by the following equations:

$$\text{HC Reduction, } (R)_{HC} = \frac{E_{BHC} - E_{DHC}}{E_{BHC}}, \text{ per unit} \qquad (3.3)$$

Where the subscript B denotes vehicle baseline emission level for the pollutant and the subscript D denotes emission level with the device installed.

$$\text{CO Reduction, } (R)_{CO} = \frac{E_{BCO} - E_{DCO}}{E_{BCO}}, \text{ per unit} \qquad (3.4)$$

$$\text{NOx Reduction, } (R)_{NOx} = \frac{E_{BNOx} - E_{DNOx}}{E_{BNOx}}, \text{ per unit} \qquad (3.5)$$

To allow for the flexibility of giving emphasis to specific pollutants, weighting factors (β_i) may be applied to each pollutant. Combining Equations (3.3), (3.4), and (3.5) and applying the weighting factors and the scaling factor (S_1), the Emission Index equation is formulated as follows:

$$\text{Emission Index, EI} = S_1 \left[\frac{(\beta_{HC})\ (R)_{HC} + (\beta_{CO})\ (R)_{CO} + (\beta_{NOx})\ (R)_{NOx}}{\beta_{HC} + \beta_{CO} + \beta_{NOx}} \right] \qquad (3.6)$$

The emission levels are expressed in grams per mile or parts per million depending on the type of test procedure used. In the retrofit test program, the 1972 Federal Test Procedure, which provides pollutant mass measurements in grams per mile, was used (Reference 4).

3.2.2 Driveability Index

An evaluation of the effect of device installation on vehicle operation required that a driveability test be performed. The vehicle driveability test used for this study followed the Automobile Manufacturers Association (AMA) procedures outlined in Section 4. Driveability characteristics were determined during vehicle operation with and without the retrofit device installed.

In the Driveability Index (DI), the sum of the "without device" driving problems is subtracted from the sum of the "with device" driving problems to arrive at a driveability variation ΔD, for each parameter:

$$\Delta D = D_{\text{with device}} - D_{\text{without device}}$$

Nine parameters were measured during the cold driveability test and during the hot driveability test. They are:

ΔD_{RI} = Rough Idle (cold start and hot start test)

ΔD_{STM} = Stumble (cold start and hot start test)

ΔD_{H} = Hesitation (cold start and hot start test)

ΔD_{D} = Detonation (cold start and hot start test)

ΔD_{S} = Stretchiness (cold start and hot start test)

ΔD_{SU} = Surge (cold start and hot start test)

ΔD_{TN} = Average cranking time (T) times number of engine start attempts (N) (cold start and hot start test)

ΔD_{STI} = Stall at Idle (cold test only)

ΔD_{A} = Acceleration from 0-60 mph, in seconds (hot start only)

These parameters are defined in detail in Appendix G of Volume IV.

Each of the above general driveability parameters represents the difference between the sum of driveability problems with the device installed on the vehicle and the sum of problems without the device installed. The sum in each case is the total of the trace, moderate, or heavy ratings for each driveability problem, quantified as follows:

Rating		Points
No problem	=	0
Trace	=	1
Moderate	=	2
Heavy	=	3

Each rating is then weighted by its appropriate coefficient (α_1 through α_{16}). The selected set of weighting coefficients used in the retrofit program is:

Cold Driveability							Hot Driveability						Start Cold	Start Hot	Acceleration
Rough Idle	Stall Idle	Stumble	Hesitation	Detonation	Stretchiness	Surge	Rough Idle	Stumble	Hesitation	Detonation	Stretchiness	Surge			
$\alpha 1$	$\alpha 2$	$\alpha 3$	$\alpha 4$	$\alpha 5$	$\alpha 6$	$\alpha 7$	$\alpha 8$	$\alpha 9$	$\alpha 10$	$\alpha 11$	$\alpha 12$	$\alpha 13$	$\alpha 14$	$\alpha 15$	$\alpha 16$
0.3333	1.6666	0.0083	0.0083	0.5	0.0083	0.0083	2.0	0.1	0.1	0.1	0.05	0.05	1.0	1.0	5.0

The hot driveability characteristics are generally weighted heavier than those of the cold start, because the relative time in the hot start mode (during normal driving) is generally much longer, making those characteristics more significant.

It must be recognized that these driveability coefficients were designed for this program. Other evaluators may select alternate coefficients to fit their specific requirements.

When applying the weighting factors and scaling factor to the driveability characteristics listed above, the Driveability Index (DI) is expressed as follows:

$$\begin{aligned} DI = \left(S_2\right)\Big[&\left(\alpha_1\ \Delta D_{RI} + \alpha_2\ \Delta D_{STI} + \alpha_3 \Delta D_{STM} + \alpha_4\ \Delta D_H + \alpha_5\ \Delta D_D\right. \\ &\left. + \alpha_6\ \Delta D_S + \alpha_7\ \Delta D_{SU}\right)_{cold} + \left(\alpha_8\ \Delta D_{RI} + \alpha_9\ \Delta D_{STM} + \alpha_{10}\ \Delta D_H\right. \\ &\left. + \alpha_{11}\ \Delta D_D + \alpha_{12}\ \Delta D_S + \alpha_{13}\ \Delta D_{SU}\right)_{hot} + \left(\alpha_{14}\ \Delta D_{TN}\right)_{cold} \\ &+ \left(\alpha_{15}\ \Delta D_{TN}\right)_{hot} + \alpha_{16}\ \Delta D_A\Big] \cdot \left[\frac{1}{\alpha_1 + \alpha_2 + \ldots + \alpha_{16}}\right] \end{aligned} \qquad (3.7)$$

3.2.3 Cost Index

The Cost Index combines those parameters which determine the initial costs of a device and the recurring costs. These parameters are measured in terms of device retail cost for the kit, installation cost (based on number of hours to install times the hourly rate), the cost of maintenance, the cost of repair, and the cost of operation over the service life of the device.

The initial cost (C_{DI}) is amortized over the expected life of the device in miles. The initial cost term is:

$$\frac{C_{DI}}{MMBTF} = \text{dollars per mile} \tag{3.8}$$

where: C_{DI} = initial cost for parts and installation, in dollars

MMBTF = mean-miles-before-total-failure, miles

The recurring costs are the added expenses for keeping the retrofit device in operation after installation, and may be expressed in terms of dollars per mile driven. These costs consist of the following:

a. Maintenance cost of labor and maintenance parts

b. Repair cost of labor and repair parts

c. Differential cost of gasoline per mile driven

The recurring cost may be written as:

Recurring costs = maintenance costs + repair costs + differential fuel costs, as shown below:

$$C_{Recur} = \left(\frac{MTTR}{MMBPF} + \frac{MTTM}{MMBM}\right) L_C + \frac{C_{RP}}{MMBPF} + \frac{C_{MP}}{MMBM} + (\sigma_D - \sigma_B)\ G_C \tag{3.9}$$

Where:

MTTR = Mean-time-to-repair, hours

MMBPF = Mean-miles-before-partial-failure, miles

MTTM = Mean-time-to-maintain, hours

MMBM = Mean-miles-before-maintenance, miles

L_C = Labor rate, dollars per hour

C_{RP} = Average cost of repair parts, dollars per repair

C_{MP} = Average cost of maintenance parts, dollars per maintenance action

σ_D = Fuel consumed with device installed, gallons per mile

σ_B = Fuel consumed without device installed (baseline), gallons per mile

G_C = Fuel cost, dollars/gallon

The units for the recurring cost items are dollars per mile.

The initial costs (Eq. 3.8) and the recurring costs (Eq. 3.9) are then combined to form the Cost Index:

$$CI = S_3 \left(\frac{C_{DI}}{MMBTF} + C_{Recur} \right), \text{ dollars per 100 miles} \qquad (3.10)$$

Where: S_3 = Scaling factor = 100

3.3 COST EFFECTIVENESS INDEX

The Cost Effectiveness Index (CEI) provides an additional information item to complement the Performance Index (PI). Should two or more devices have essentially the same PI, the one with the highest CEI would be preferred.

Cost effectiveness is usually defined as the ratio of the desired results, or the desired output, versus the required cost input. In this study, the CEI is defined as the ratio of the Emission Index to the Cost Index (the same indexes used in the Performance Index equation).

$$CEI = \frac{\text{Emission Index, (Per unit of reduction)}}{\text{Cost Index, (\$/100 miles)}}$$

Using the expressions of the Emission and Cost Indexes previously developed (Eqs. (3.6) and (3.9), respectively), the Cost Effectiveness Index is calculated as follows:

$$CEI = \frac{S_1 \left\{ \beta_{HC} \left(\frac{E_{BHC} - E_{DHC}}{E_{BHC}} \right) + \beta_{CO} \left(\frac{E_{BCO} - E_{DCO}}{E_{BCO}} \right) + \beta_{NO_X} \left(\frac{E_{BNOx} - E_{DNOx}}{E_{BNOx}} \right) \right\} \left\{ \frac{1}{\beta_{HC} + \beta_{CO} + \beta_{NOx}} \right\}}{S_3 \left\{ \frac{C_{DI}}{MMBTF} + \left(\frac{MTTR}{MMBPF} + \frac{MTTM}{MMBM} \right) L_C + \frac{C_{RP}}{MMBPF} + \frac{C_{MP}}{MMBM} + \left(\sigma_D - \sigma_B \right) G_C \right\}} \qquad (3.11)$$

3.4 ESTABLISHING WEIGHTING COEFFICIENTS FOR THE PERFORMANCE INDEX

To compute the overall Performance Index (PI), careful decisions and judgments must be exercised in applying the weighting coefficients (C_i) to the Emission, Driveability, and Cost Indexes. This is required because the weighting coefficients can significantly influence the relative ranking of devices.

The usefulness of the weighting coefficients is evident when driveability and costs are penalized in comparison to emission reduction. If the emission reduction is to be the primary desired benefit, small sacrifices of driveability or costs may be considered acceptable. For example, a device may have high emission reduction benefits with slight driveability degradation and high operating cost. In this case, an air pollution control agency would weight emission reduction high, and weight driveability and costs low. The agency can then screen out devices best suited to abate its used car emission problems.

In order to add together and to properly compare the index terms of different units or different scales, it is necessary to assign certain scale factors to bring these terms into a common range. The notations, S_1, S_2, and S_3, are used to represent the scale factors within the Emission, Driveability, and Cost Index terms. Based on the observation of the test data in this program, values of 1, 1/3, and 100 were assigned to S_1, S_2, and S_3, respectively.

After these scale factors are applied, the three terms may then be subjected to modification of weighting coefficients in order to reflect an evaluator's opinion as to the relative degree of importance to be given each index.

Four combinations of weighting coefficients with one set of scaling factors were considered for use in the retrofit device performance analysis and are tabulated in Table 3-2. The first combination of C_i values listed below is the one used for the evaluation of devices in the retrofit study (see paragraph 6.4 for results). The four combinations considered for use were as follows:

a. Emission reduction is twice as important as cost, which is twice as important as driveability. By this policy, driveability is unity, 1, and cost then is 2 x 1, or 2, while the emission reduction is twice cost, (2 x 2, or 4). The weighting coefficients are therefore: $C_1 = 4$, $C_2 = 1$, $C_3 = 2$. (See Table 3-2.)

b. Emission reduction is three times as important as cost, which is three times as important as driveability. Driveability is again unity; therefore, cost is 3 x 1 = 3, and emission reduction is 3 x 3 = 9. Therefore: $C_1 = 9$, $C_2 = 1$, $C_3 = 3$.

c. Emission reduction is four times as important as cost, which is four times as important as driveability. Driveability is unity, cost is 4 x 1 = 4, and emission reduction is 4 x 4 = 16. Therefore: $C_1 = 16$, $C_2 = 1$, $C_3 = 4$.

d. Emission reduction is ten times as important as cost, which is just as important as driveability. Driveability equals unity, cost equals 1 x 1 = 1, and emission reduction equals 10 x 1 = 10. Therefore: $C_1 = 10$, $C_2 = 1$, $C_3 = 1$.

Table 3-2. WEIGHTING COEFFICIENTS FOR THE PERFORMANCE INDEX

WEIGHTING POLICY	EMISSION REDUCTION C_1	DRIVEABILITY C_2	COST C_3
a. Emission reduction is twice as important as cost, which is twice as important as driveability	4	1	2
b. Emission reduction is three times as important as cost, which is three times as important as driveability	9	1	3
c. Emission reduction is four times as important as cost, which is four times as important as driveability	16	1	4
d. Emission reduction is ten times as important as cost, which is just as important as driveability	10	1	1
Scale Factor	$S_1 = 1$	$S_2 = 1/3$	$S_3 = 100$

SECTION 4

RETROFIT PERFORMANCE ANALYSIS

Data inputs for the evaluation methodology described in the preceding section were developed in two ways. An engineering analysis was conducted on each retrofit device for which adequate data were obtained from the developer, and a test program was conducted on those devices for which:

a. A practical feasibility for retrofit use was indicated by the screening evaluation described in Volume IV.

b. Test hardware could be provided by the developer at a time compatible with the study schedule.

The objective of this data development effort was to provide the quantitative and qualitative information required to determine the effectiveness and costs of the various retrofit devices by means of the evaluation methodology. The approach to the engineering analysis and test program, and the presentation of the results of the retrofit device performance analysis are summarized below.

4.1 ENGINEERING ANALYSIS

The purpose of the engineering analysis of devices was to describe each retrofit device or system in terms of its technical characteristics, so that (1) the data provided by development sources could be evaluated for acceptability and (2), when possible, additional or supplementary data could be developed. The data developed through the engineering analysis were used as inputs to the evaluation methodology, and were documented in the Volume II system descriptions of each device. When information obtained from the developer was inadequate for analysis and supplementary information could not be developed within the study time schedule, the device was partially evaluated. Appendix C identifies the 65 devices for which complete or partial evaluation was possible.

4.1.1 Engineering Analysis Team

The engineering analysis and system description of each device were prepared by a team of engineers representing the technologies of retrofit device design. The team consisted of a system analyst, a mechanical systems engineer, an electrical systems engineer, and a reliability/maintainability analyst.

4.1.2 Engineering Analysis Approach

The technical characteristics of each retrofit device were analyzed in terms of its physical and functional characteristics, emission reduction performance characteristics, reliability, maintainability, driveability, safety, installation requirements, and initial and recurring costs:

a. Physical and Functional Description: The analysis of each device evaluated was initiated by describing its physical and functional characteristics. Physical information documented included size, weight, and fabrication or construction details, including material composition. Functional characteristics were documented by identifying the principal components of the device and how they operate. Photographs and schematics were used to illustrate both physical and functional characteristics.

b. Emission Reduction Performance Characteristics: These characteristics were analyzed and documented in terms of the percentage emission reduction provided by the device. This calculation was made by comparing vehicle emission data with and without the device installed (refer to Section 6 for the percentage emission reduction formula used in this calculation). Emission data for the calculation were obtained from the retrofit test program if the device was one of those tested; and, if not, from test data provided by the developer. The data were categorized by type of test procedure, with preference given to data obtained by the 1972 Federal Test Procedure. The principal test procedures were as follows:

   1. 1972 Federal Test Procedure (CVS) as specified in Reference 4.

   2. 1970 Federal Test Procedure (7-cycle, 7-mode cold or hot start) as specified in Reference 5.

   3. EPA 9-cycle, 7-mode procedure, as specified in Reference 6.

   4. Steady state procedures in which devices were tested at various engine rpm's, as specified by the developer.

c. Reliability: The method for evaluating reliability of a device was to analyze the functions performed by the device and the components and structural configuration which implement those functions. Since failure rate data for retrofit applications were not obtainable, the components were evaluated by comparison with analogous types of components having known failure rates. Each retrofit device was evaluated against the service life requirement of 50,000 mean-miles-before-total-failure (MMBTF).

d. Maintainability: To estimate retrofit maintainability requirements, each retrofit device was examined for preventive maintenance requirements by considering it comparable to a conventional automotive counterpart. For each retrofit device examined, the following information was determined and listed:

   1. Preventive or scheduled maintenance action description.

   2. Preventive maintenance action interval, quantified by mean-miles-before-maintenance (MMBM).

3. Labor associated with the preventive maintenance action, quantified as mean-time-to-maintain (MTTM).

4. Material and parts cost related to the preventive maintenance action, quantified as cost-of-maintenance-parts (C_{MP}).

e. Driveability: Driveability analysis was limited to those devices tested in the retrofit program, because driveability data obtained from development sources were inadequate. Vehicle driveability characteristics were determined with and without a retrofit device installed. The detailed driveability test procedures used are presented in Volume IV. Driveability test results were discussed with the personnel conducting the tests, and driveability characteristics were summarized for each test condition as part of the evaluation process.

f. Safety: Analysis of the retrofit devices on the merits of safety was based on such factors as exhaust gas leakage, leakage of raw fuel, and introduction of raw fuel to a source of ignition which could result in a fire hazard. The analysis included possible device related engine failure or loss of power which could occur under hazardous driving conditions. Excessive device-induced temperatures were also identified, based on possible adverse effects on the vehicle and the occupants.

g. Installation Procedure: Much of the installation data supplied by developers included detailed installation procedures on a step-by-step basis. If no procedures were described by the developer, but installation sketches were provided, step-by-step procedures were developed. In instances were the device had been tested at the Anaheim facility, the actual installation procedure was used.

h. Initial Costs: The number of hours required for retrofit device installation, test, and adjustment was estimated from the detailed installation procedure. The estimated hours were compared to the estimate provided by the developer. Any significant differences were resolved by contact with the developer. The labor cost was determined by multiplying an hourly rate of $12.50 by the number of hours. The estimated retail cost of the material was taken from the developer's source material, unless this retail cost was considered unrealistic. In the latter case, a cost estimate based on historical cost data for similar items was used.

i. Recurring Costs: Recurring costs are defined as those costs associated with retrofit repair, maintenance, and increased or decreased fuel consumption. When recurring costs were computed, it was decided that the effect of increased fuel consumption would not be included in recurring costs for those devices which were not tested in the retrofit program. This decision was made because most developers did not submit fuel consumption data, and many of those who did reported questionable improvements in economy. However, fuel consumption was measured for the 11 devices tested in the laboratory and was included in their recurring cost calculations.

j. Feasibility Summary: The technical characteristics analysis of each device was concluded by summarizing the practical feasibility of the device for retrofit application to used cars. This summary was a qualitative consideration in the evaluation of the relative effectiveness and costs of retrofit devices.

4.2 TEST PROGRAM

Comprehensive retrofit system emission, driveability, and durability tests were performed to supplement the data base established through the engineering evaluation. The following presents a summary of the test vehicle fleet, retrofit system selection, test approach, and test procedures. The more detailed test program procedures are presented in Volume IV.

4.2.1 Test Vehicle Fleet

The contract permitted the maximum purchase of 24 pre-1968 uncontrolled test vehicles. These test vehicles were used to evaluate the emission and driveability characteristics of the candidate retrofit systems. The test vehicle fleet was to be divided into two replicate fleets. These two fleets were to be as identical as possible with respect to vehicle model years, engines and carburetors, and transmissions. The rationale for the replicate fleets was to isolate differences which might occur in retrofit system performance because of vehicle driving conditions, geographical location, vehicle climatological exposure history and other possible biases, at two widespread points in the U.S.A. The geographic locations used were the Olson Laboratories test facilities in Anaheim, California, and Taylor, Michigan.

4.2.1.1 Test Vehicle Screening

Prior to the purchase of a test vehicle, a three-step screening inspection was conducted. First, an overall vehicle inspection was performed. This included a visual check of safety related items, including tires, wheel alignment, and brakes. Second, the vehicle received an engine condition inspection. Measured blowby flow rates were compared to the California Blowby Device Certification Procedures (Volume IV, Appendix F). The engine condition criterion was to accept cars which were in reasonable condition and would not need any major engine repair throughout the test program. Third, if the vehicle passed these initial inspections, it received an HC and CO emission test at idle and at 2,500 rpm (free running). An ignition system analysis was conducted with an engine analyzer oscilloscope.

The vehicles were accepted if they met the overall vehicle and engine condition criteria. However, carburetor and ignition system malfunctions were not grounds for rejection.

4.2.1.2 Fleet Composition

The model-year selection criteria for the test vehicle fleet were:

a. Number of light duty vehicles (6,000 pounds and less gross vehicle weight) on the road by model year and make prior to 1968.

b. Popularity of engine and transmission combinations within that vehicle population.

c. No exhaust emission control devices originally installed by the car manufacturer.

d. Value of the automobile.

Since exhaust controls were incorporated nationally on 1968 vehicles, the total vehicle population of concern was restricted to pre-1968 cars. This provided a vehicle fleet without factory installed exhaust emission controls.

To minimize emission level variations attributable to different model years and because of the small size of the test fleet and the range of makes and model years to be covered, it was decided to select a single model year to represent each of two classes of vehicles: (1) those with no devices at all and (2) those with positive crankcase ventilation (PCV) devices only. The 1965 model year was selected to represent the cars with PCV control systems, and the 1961 model year was selected to represent the cars without PCV controls. An additional reason for the 1965 model-year selection was to avoid the 1966 and 1967 model cars which were sold new in California with exhaust emission control systems.

Table 4-1 describes the test fleet by model year, engine size, and location. The Anaheim and Taylor fleets were identical in most respects. The details of the vehicle selection are outlined in Volume IV, Section 3.

4.2.1.3 As-Received Vehicle Exhaust Emissions

The retrofit fleet vehicles received cold start exhaust emission tests by the 1972 Federal Test Procedure and a 7-mode hot start exhaust emission test by the 1970 Federal Procedure (Reference 5), immediately following their acceptance and purchase. The vehicles were tested as-received with no repairs or adjustments prior to the exhaust tests. The vehicles were then tuned to the automobile manufacturer's

Table 4-1. TEST VEHICLE FLEET (1)

Location	Car Number (Fleet)	Year	Make	Model	Engine Size CID	Engine Size Class	Transmission	As Received Odometer Miles	Carburetor (Model and Number)
Anaheim	1	65	Chevrolet	Nova	194	B	Standard	12,053	Rochester 1V 7025105
Anaheim	2	65	Ford	Fairlane	289	D	Automatic	62,224	Autolite 2V C52F-9510-B
Anaheim	3	65	Plymouth	Fury	318	E	Automatic	84,054	Carter 2V BBD 38445
Anaheim	4 (2)	65	Chevrolet	Impala	327	E	Automatic	82,245	Rochester 4V 4CC 7025122
Anaheim	5	65	Ford	LTD	390	F	Automatic	92,124	Autolite 4V C5AF-9510-AC
Anaheim	6	61	Chevrolet	Impala	283	D	Automatic	114,070	Rochester 2V 2GC 7019008
Taylor	7 (3)	65	Chevrolet	Nova	194	B	Standard		
Taylor	8	65	Ford	Fairlane	289	D	Automatic	38,343	Ford 2V C5ZEH
Taylor	9	65	Plymouth	Fury III	318	E	Automatic	45,576	Carter 2V 38485A-5
Taylor	10	65	Chevrolet	Impala	327	E	Automatic	56,300	Carter 4V AFB 3721-SB-HC
Taylor	11	65	Ford	Galaxie	390	F	Automatic	49,560	Ford 4V C5AF-H A-4GB
Taylor	12	61	Chevrolet	Impala	283	D	Automatic	45,120	Rochester 2V
Anaheim	13 (3)	65	Chevrolet	Nova	194	B	Standard		
Taylor	14	65	Ford	Fairlane	289	D	Automatic	55,601	Ford 2V C5ZFH
Taylor	15	65	Plymouth	Fury	318	E	Automatic	103,895	Bendix 2V WW 3-251-A
Taylor	16	65	Chevrolet	Impala	327	E	Automatic	100,207	Rochester 4V 7025121
Anaheim	17 (2)	65	Ford	Galaxie	390	F	Automatic	57,119	Autolite 4V C5AF-9510-AC
Anaheim	18 (2)	61	Chevrolet	Impala	283	D	Automatic	82,833	Rochester 2V 2GC 7019008
Anaheim	19	65	VW	1500	91	A	Standard	89,224	Solex 28 PICT-1
Taylor	20	65	VW	1500	91	A	Standard	65,154	Solex 28 PICT-1 13, 129, 023H
Anaheim	21 (2)	65	Chevrolet	Impala	327	E	Automatic	62,552	Rochester 4V 4GC 7025122
Anaheim	22 (2)	65	Chevrolet	Super Sport	327	E	Automatic	92,313	Rochester 4V 4GC 7025121

(1) All vehicles were initially inspected for assurance of standard equipment as supplied by the automobile manufacturers (tires, running gear components, etc.).

(2) Durability test vehicles.

(3) Cars 7 and 13 were not purchased.

specifications and retested by the 1972 Federal Test Procedure prior to beginning the retrofit system evaluation tests (Reference 4).

Table 4-2 lists the as-received and after tuneup exhaust emission results obtained in these tests. The average emission levels for the retrofit fleet are compared in this table to historical emission data obtained in the study of periodic vehicle emission inspection and maintenance (PVI) performed by Northrop/Olson for the California Air Resources Board (References 7 and 8). The retrofit fleet showed an average hydrocarbon level of 6.65 grams per mile (gm/mi) and compared closely to the 6.76 gm/mi measured on 122 vehicles of the 1965 model year tested in the PVI study under equivalent 7-mode hot start procedures.

Table 4-2. TEST FLEET EXHAUST EMISSIONS

CAR NO.	MAKE (CUBIC INCH DISPLACEMENT)	AS RECEIVED						AFTER TUNEUP		
		7-MODE HOT START GRAMS/MILE(1)			72 FEDERAL COLD START GRAMS/MILE(2)			72 FEDERAL COLD START GRAMS/MILE		
		HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
1. Anaheim										
1	65 Chev 194	7.38	162.87	0.73	12.48	110.24	0.60	(3)	202.99	0.65
2	65 Ford 289	5.06	58.56	6.06	7.02	90.56	4.12	6.53	73.65	4.45
3	65 Ply 318	4.08	11.75	7.22	5.85	31.33	10.72	6.12	94.73	5.93
4	65 Chev 327	4.62	31.27	9.16	6.89	44.43	1.63	6.15	66.49	3.25
5	65 Ford 390	3.63	35.80	5.92	5.39	86.16	5.28	14.14	150.50	3.72
6	61 Chev 283	4.71	20.52	6.36	5.41	55.20	5.94	(3)	72.39	2.92
17	65 Ford 390	10.42	206.76	1.06	(3)	238.41	0.51	10.88	163.37	3.16
18	61 Chev 283	6.77	142.53	1.39	8.25	168.12	1.03	(3)	83.86	1.46
19	65 VW 92	(4)	(4)	(4)	(4)	(4)	(4)	10.81	76.12	1.69
21	65 Chev 327	(4)	(4)	(4)	(4)	(4)	(4)	9.06	92.11	3.68
22	65 Chev 327	(4)	(4)	(4)	(4)	(4)	(4)	7.91	64.95	3.65
2. Detroit										
8	65 Ford 289	9.90	76.85	5.90	(4)	(4)	(4)	3.69	38.40	3.24
9	65 Ply 318	10.54	158.49	1.60	(3)	(3)	(3)	6.02	97.62	4.29
10	65 Chev 327	8.51	176.44	1.75	10.13	397.30	0.69	3.95	52.52	(3)
11	65 Ford 390	6.42	117.78	1.99	12.70	313.34	2.60	7.61	125.34	4.12
12	61 Chev 283	7.15	101.89	1.97	8.65	231.67	2.36	8.17	72.41	3.42
15	65 Ply 318	7.66	68.98	7.05	(4)	(4)	(4)	(4)	(4)	(4)
16	65 Chev 327	5.69	64.11	3.94	(4)	(4)	(4)	5.18	46.82	5.03
20	65 VW 92	3.84	24.30	3.98	3.31	76.39	2.30	6.12	37.50	2.18
Exhaust Emission Averages:										
1. Average of both Detroit and Anaheim Retrofit Fleets:		6.65	91.18	4.13						
2. Average of 1965 Vehicles for 122 cars in the Northrop/Olson California ARB VIEM Study, Vol. V., Table 4-26(5):		6.76	80.92	3.48						

(1) 1970 Federal Test Procedure.
(2) Federal Register (Reference 4)
(3) Test data invalid.
(4) Test not performed.
(5) Final Report No. 71Y240A (Reference 8)

The carbon monoxide levels for the retrofit fleet were higher than the PVI fleet (91.2 versus 80.9, respectively). An examination of the mode-by-mode data from the as-received 7-mode tests showed that several of the fleet vehicles had extremely rich air-fuel ratios in the main circuit of the carburetor. In addition, idle CO levels were generally very high. These conditions were corrected by tuneup.

The oxides of nitrogen levels of the retrofit fleet were higher than the PVI study average levels for the 1965 cars (4.13 versus 3.48, respectively).

This comparison shows that the retrofit fleet emission levels compare reasonably well with the referenced PVI study of 1965 model-year cars. Of course, the distribution of the 122-car PVI sample is more representative of the 1965 car population than that of the 16-car sample listed in Table 4-2.

4.2.1.4 Baseline Test Variability

Early in the retrofit test schedule it became apparent that the vehicles used in the retrofit test program had substantial variability in baseline emission levels from test-to-test and car-to-car. It was also recognized that the effect of installing retrofit devices may have influenced the vehicle's baseline emission levels even though the device was only on the vehicle and operating for a few miles between each baseline test (less than 50 miles in most cases). The car was restored to its previous tuneup baseline condition prior to each baseline test.

Appendix A presents the baseline exhaust emission test data for the test vehicles. Most vehicles received from five to nine baseline tests. Car No. 4 received nine baseline tests. Cars 19 and 20 received two baseline tests because only two devices were available for foreign car device tests.

Inspection of the individual baseline test results for each car suggested that some of the baseline emission data points might have been "outliers". The Dixon tests for "outliers" are the best and the easiest way for testing the hypothesis that all values of a normal population are drawn from a single population (Reference 9). The probability levels (5 percent and 1 percent) are for the chance that the "outlier" or extreme data point will be excluded from the data set when the hypothesis is true (the chances of excluding a really good value). Sound practice demands that "outliers" should only be excluded on strictly statistical grounds as a last resort. Engineering judgment and common sense must prevail, with the continual reminder that random sampling with small samples leads to much higher variability than expected. As a result extreme configurations of data points in the samples are often encountered. If the calculated value of the Dixon test statistic fell below the 1 percent probability level, there was good statistical grounds that the data point in question was really an "outlier", but the action taken depended on the engineering facts of the raw data.

Only two clear cases of "statistical outliers" were evident, HC in Test 1 of Car 5 and NOx in Test 1 of Car 10 (Appendix A). It was decided on technical grounds to retain the Car 5 emission results and exclude the baseline data for Car 10, Test 1. The NOx value of 17.37 gm/mile for Test 1 of Car 10 was the highest baseline NOx level measured, and was 3.4 times the average of the other five tests made on that car (Appendix A).

4.2.1.4 Taylor, Michigan, and Anaheim, California, Fleet Comparison

A comparison of fleet differences between Anaheim and Taylor was made by comparing the average baseline emission levels for the same five cars in both fleets. The results of the comparison are shown in Table 4-3. Car 1 (65 Chevrolet Nova 194 CID) in the Anaheim fleet was excluded from this analysis because there was no equivalent car available for tests in the Taylor fleet. The VW's were also excluded because only two baseline tests were conducted. The Welch test statistical calculation showed no significant difference for NOx at the 90 percent level. The HC level average for the five Taylor cars (5.13 gm/mi) was significantly lower than the five Anaheim cars (7.60 gm/mi). The CO levels for the Taylor fleet were also significantly lower than the Anaheim fleet (62.54 versus 93.35 gm/mi, respectively).

The differences between the Taylor and Anaheim fleets might be partially explained by the tuneup procedures conducted after the as-received emission tests. The carburetors for the Taylor fleet were rebuilt and calibrated on a flow bench by a commercial carburetor rebuilder. The Anaheim fleet carburetors were rebuilt by an independent automotive repair shop without a flow bench. Ignition systems were rebuilt in both cities by OLI technicians with the aid of an ignition analyzer scope. However, all carburetor and ignition systems in both cities were rebuilt, calibrated, and adjusted to the automobile manufacturer's specifications.

The retrofit devices were evaluated on the basis of percent reduction with respect to each car's baseline each time a device was installed. Therefore, the effects due to baseline differences were minimized between the two cities.

4.2.2 Selection of Retrofit Test Devices

Table 4-4 lists those retrofit systems selected for retrofit test programs. Crankcase devices were eliminated from test evaluations because adequate data were already available from the engineering evaluation. Fuel additives were eliminated from the test program because the required mileage accumulation to show possible emission reduction effects was beyond the scheduled time limits of the study. Fuel additives were included, however, in the engineering evaluation. The device selections were accomplished by means of the selection criteria described in Volume IV. Four retrofit systems were selected to receive evaluations on up to 13 fleet vehicles and 10 were selected for evaluations on 2 vehicles. All candidate retrofit devices selected were tested in the emissions test laboratory except those noted in Table 4-4.

4.2.3 Test Approach

As described in Section 3, the evaluation methodology used to evaluate device performance required measured data with and without the retrofit system installed. Basically, two types of tests were required to support inputs to the Performance Index (PI) analysis. There were:

a. Baseline tests: which were conducted on a standard test vehicle without the retrofit emission control system. The baseline vehicle tuneup adjustments were set to the automobile manufacturer's specifications. The baseline vehicle was not tuned for low emissions.

Table 4-3. TAYLOR VS ANAHEIM TEST VEHICLE BASELINE EMISSION LEVEL DIFFERENCES IN MEAN GRAMS/MILE (APPENDIX A)

LOCATION	CAR NO.	MAKE/CID	HC MEAN	CO MEAN	NOx MEAN
Anaheim	(1)				
	2	65 Ford 289	8.61	125.16	2.91
	3	65 Ply 318	6.99	92.02	4.40
	4	65 Chev 327	7.52	66.28	3.06
	5	65 Ford 390	8.99	106.63	2.70
	6	61 Chev 283	5.91	76.68	2.06
	Mean Cars 2 thru 6		7.60	93.35	3.03
Taylor	8	65 Ford 289	3.92	58.67	4.04
	9	65 Ply 318	4.41	58.88	4.59
	10	65 Chev 327	5.27	49.91	4.87
	11	65 Ford 390	6.08	89.93	3.14
	12	61 Chev 283	5.98	55.33	3.04
	Mean Cars 8 thru 12		5.13	62.54	3.94
DIFFERENCE (ANAHEIM MINUS TAYLOR):			2.47	30.81	-0.91
STATISTICAL SIGNIFICANCE AS CALCULATED BY WELCH'S TEST (2)			Significantly Different	Significantly Different	Not Significantly Different

(1) Car No. 1, Anaheim, omitted as there was no vehicle equivalent in Taylor, Michigan.

(2) Reference 10 (See Appendix H for sample calculation of Welch's approximate t solution of the Fisher-Behrens problem.)

(3) The negative sign shows that, for NOx, the Taylor fleet was higher than the Anaheim fleet.

Table 4-4. RETROFIT DEVICES SELECTED FOR TEST PROGRAM

DEVICE NO.	DEVICE TYPE
Evaluations on up to 13 Test Vehicles	
1 (1)	Air Bleed to Intake Manifold
70 (2)	Catalytic Muffler
96 (3)	Catalytic Converter with Distributor Vacuum Advance Disconnect
175	Ignition Timing Modification with Lean Idle Adjustment
246	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect
Evaluations on up to 3 Test Vehicles:	
10	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect
33	Carburetor Modification, Main Jet Differential Pressure
42	Air Bleed to Intake Manifold
69	Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification
91 (4)	Variable Orifice Carburetor
245	Variable Camshaft Timing
288	Carburetor Main Discharge Nozzle Modification
295	Carburetor with Variable Venturi
418 (2)	Air Bleed to Intake Manifold

(1) Selected for tests on 13 vehicles at Technical Review Board Meeting on 21 October 1971. This device was originally selected for evaluation on two vehicles.

(2) Declined participation.

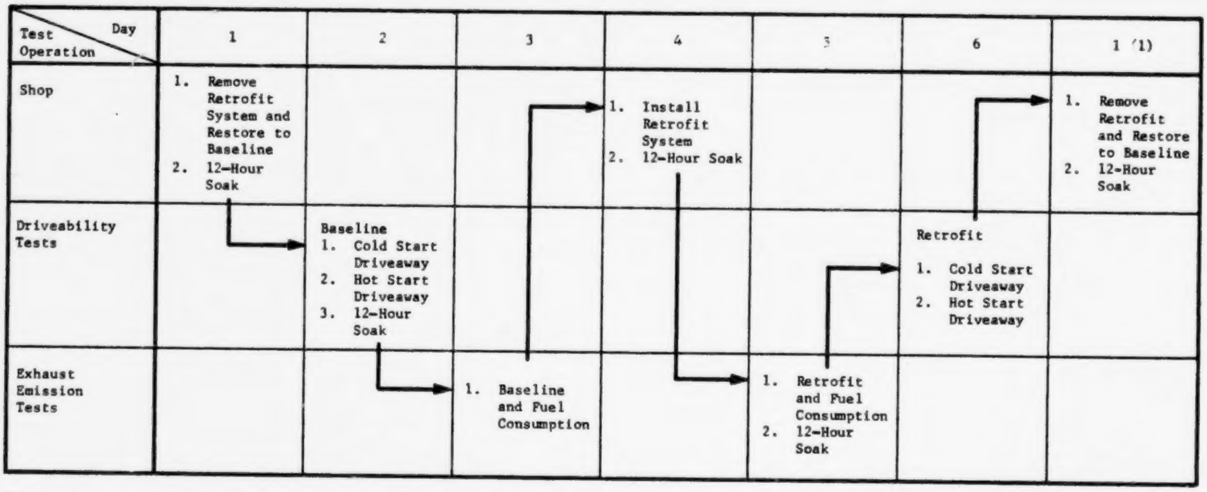
(3) Selection of device verbally agreed upon between Project Engineer and Project Officer, 4 October 1971.

(4) Device not available during retrofit test program.

b. Retrofit tests: which were conducted on the standard test vehicle with the candidate retrofit device installed and in operation. Retrofit system installation and tuneup adjustments were conducted in accordance with the retrofit developer's specifications.

As each vehicle was procured, it was tested for as-received exhaust emissions and driveability. It was then tuned to the auto manufacturer's specifications to minimize the possibility of tuneup malfunction during the subsequent retrofit system tests. The vehicle then received a baseline (after tuneup) exhaust test and driveability tests. After each baseline test, each vehicle was equipped with the candidate retrofit system, for the retrofit exhaust emission and driveability tests. The tests alternated between the baseline and retrofit system tests until testing of all candidate systems was complete.

Figure 4-1 illustrates the test sequence of a test vehicle and the time required for complete baseline and retrofit system test processes. The flow chart was typical for all devices that were tested. Six cars at Anaheim and five cars at Detroit were processed each day. Details of the test sequence and procedures are presented in Section 3 of Volume IV.



Test Operation / Day	1	2	3	4	5	6	1 (1)
Shop	1. Remove Retrofit System and Restore to Baseline 2. 12-Hour Soak			1. Install Retrofit System 2. 12-Hour Soak			1. Remove Retrofit and Restore to Baseline 2. 12-Hour Soak
Driveability Tests		Baseline 1. Cold Start Driveaway 2. Hot Start Driveaway 3. 12-Hour Soak				Retrofit 1. Cold Start Driveaway 2. Hot Start Driveaway	
Exhaust Emission Tests			1. Baseline and Fuel Consumption		1. Retrofit and Fuel Consumption 2. 12-Hour Soak		

(1) Six-day test sequence starts over for the next scheduled retrofit device.

886

Figure 4-1. BASELINE AND RETROFIT SYSTEM TEST SEQUENCE FOR EACH TEST VEHICLE

Installation of the candidate retrofit systems (Day 4) was conducted by Olson Laboratories technicians under the direction of the retrofit developer or his representative. Special tuneup adjustments as specified by the developer were also conducted. The vehicle was road tested by Olson technicians and the developer's representative to ensure proper operation of the device. If the operation of the equipped vehicle was acceptable to the developer, no further adjustments were allowed for the subsequent retrofit emission and driveability tests.

Originally, the evaluations were to be conducted with six devices on six cars both at the Anaheim and Taylor facilities. As required by the contract (Reference 1), this accounted for 72 tests. Because of the time required to select the appropriate test vehicles and the lead time necessary for developer's to provide devices for testing, the Environmental Protection Agency requested that replicate tests be conducted for as many devices as possible within the allowable time schedule. Accordingly, three retrofit developers received a maximum of six replicate tests each.

These replicate tests involved two baseline and two retrofit tests conducted in the following sequence: (1) baseline, (2) retrofit, (3) baseline, and (4) retrofit. Appendix B displays a detailed matrix of the test schedule by vehicle, location, date of test, and device number. Appendix B also presents a comparison of the tests conducted in the retrofit program with the contract requirements. Eleven different makes and types of devices received laboratory evaluation. Seventy-five baseline and retrofit emission and driveability tests were conducted.

The test procedures are described in Volume IV, Section 3, and are summarized below.

4.2.4 Test Procedures

The 1972 Federal Test Procedure was used to measure the baseline and retrofit system exhaust emission (Reference 4). NOx was measured in accordance with the Federal test procedure for NOx evaluation subsequently published (Reference 11).

4.2.4.1 Fuel Requirements

Test fuel requirements were as specified in the aforementioned References 4 and 11. Indolene 30 meets these requirements and was used for all emission tests, excluding the catalytic converter tests. For the catalyst systems, Indolene Clear (no lead) was used as the test fuel. Commercial leaded fuel was used in all test cars for the driveability tests, excluding the catalyst systems for which a non-leaded commercial fuel was used. Fuel consumption was measured by weight during the baseline and retrofit exhaust emission tests.

4.2.4.2 Driveability Tests

The Automobile Manufacturer's Association (AMA) standard driveability test procedure was used to evaluate the operating characteristics of the vehicle on the road (refer to Volume IV, Appendix G). Basically, the procedure consists of a cold start driveaway procedure (following an overnight soak period at ambient temperature) and then a hot start driveaway procedure. Vehicle performance was determined at wide open throttle from 0-60 mph by measuring the elapsed time. Detailed driveability test procedures are described in Volume IV, Section 3.

4.2.4.3 Safety Tests

The safety tests were conducted during the driveability tests. These tests consisted in recording the backfires and engine stalls, if any, caused by the device. These modes of operation were termed critical driveability in the performance analysis described in Section 3.

4.2.4.4 Durability Tests

The durability tests consisted in driving a retrofit-device-equipped car for 25,000 miles and measuring the exhaust emissions at 5,000-mile increments. The exhaust emissions were measured in accordance with the 1972 Federal Test Procedure (References 4 and 11). Mileage accumulation was performed on a test route which covered freeway, suburban, and city driving at an average speed of approximately 35 mph. Fuel consumption and driving problems were recorded during each shift of vehicle operation.

The durability test results are presented in Volume VI, which is to be published shortly.

4.2.4.5 Mountain and Driveability Tests

The mountain and desert driveability tests were performed on four representative devices to determine whether environmental extremes could cause an impact on vehicle driveability when the vehicle was equipped with a retrofit device. The AMA driveability cold start driveaway procedure was conducted in the mountains above 6,000 feet. The hot start driveaway procedure was conducted in the desert at altitudes ranging from near sea level to 2,500 feet.

4.3 PERFORMANCE ANALYSIS DATA INPUTS AND RESULTS

The data input for the performance analysis was developed by means of the system engineering analysis documented in Volume II, and the emission and driveability test program outlined in the previous paragraphs. The retrofit devices evaluated are listed in Appendix C by device number. Eleven devices were tested in the retrofit test program by Olson Laboratories, Inc., and data for the remaining devices were obtained from the retrofit developer and/or EPA.

The completeness of data provided in the data survey questionnaire responses varied widely. In several cases, emission data from the retrofit developer were not provided. Retrofit driveability test data were inadequate for use in the analysis because of the lack of baseline vehicle data.

Appendix D presents all of the input data to the performance analysis computer program from the data survey, the engineering analysis, and the retrofit test program. The inputs include all data developed to determine the Criteria Index, Emission Index, Driveability Index, Cost Index, and Cost Effectiveness Index.

There are three levels of confidence in data used in the performance analysis. The highest confidence level data were generated through the laboratory tests under the controlled conditions of the retrofit study. These data are listed in Appendix D. The second highest level data were generated through the objective engineering analysis presented in Volume II. The least confident data were the developer supplied emission data that were not substantiated by recognized independent testing facilities; these data are also listed in Volume II for the applicable devices.

Appendix E presents the performance analysis results of the computer calculations performed for each of the devices tested in the retrofit program, and includes a legend for interpreting the computer results. Appendix E also lists the results of the emissions tests. The results presented in Appendix E and Volume II are discussed in the subsequent evaluations of the Criteria Index, the Performance Index, and the Cost Effectiveness Index presented in Sections 5, 6, and 7.

SECTION 5

CRITERIA INDEX ANALYSIS

The critical parameters of the performance analysis were defined in the discussion of the Critical Index in Section 3. The Criteria Index is a product of factors that have values of 1.0 or 0.0 depending on whether or not certain retrofit evaluation criteria were satisfied. The Criteria Index factors include emission standards, emission baseline, safety, critical driveability, general driveability, installation cost, recurring cost, reliability, maintainability, and availability (customer inconvenience). The Criteria Index provides a gross feasibility evaluation for each device, and a rapid indication as to whether a device would meet the legislative requirements for each performance parameter.

5.1 EVALUATION CRITERIA

The Criteria Index requires that the performance parameters of a device achieve a given evaluation level before the device is acceptable. Table 3-1 lists the evaluation criteria used for each performance parameter. These criteria are based primarily on California standards and guidelines for certification of retrofit devices, as described in Section 3. The criteria, as applicable in the retrofit program, were used only to provide a basis for comparison of the retrofit devices and are not intended as recommended standards. Should these criteria not be representative of a given State's or air quality region's vehicle emission control requirements, different evaluation criteria may be used and the Criteria Index recalculated as shown in Volume I, Appendix A.

The volumetric emission standards listed in Table 3-1 are for the California used car standards, which are based on a 7-cycle, 7-mode cold start test procedure (Reference 16). The mass standards given in this table are the conversions from volumetric emissions to mass emissions for a 4,000-pound car, calculated in accordance with the 1970 Federal Test Procedure (Reference 5). These standards are not applicable to the 1972 Federal Test Procedure and therefore were not used in the retrofit program. No used car emission standards have yet been established for the 1972 Federal Test Procedure. If the evaluator intends to use the 1972 Federal Test Procedure for accrediting retrofit emission systems, then used car emission standards applicable to retrofit systems must be established for that test procedure.

5.2 CRITERIA INDEX RESULTS

Table 5-1 presents the results of the Criteria Index evaluation performed on the devices studied in the retrofit program. The value for each of the criteria factors was 1 or 0 depending on whether or not the evaluation criterion (Table 3-1) was satisfied. A Criteria Index factor value of 1 indicates that the device

Table 5-1. CRITERIA INDEX RESULTS FOR DEVICES EVALUATED IN RETROFIT PROGRAM

ITEM	DEVICE NO.	DESCRIPTION	NO. OF TESTS	CRITERIA INDEX	CRITERIA INDEX FACTORS (1)(2)									
					EMISSIONS STANDARD	EMISSION BASELINE	SAFETY FACTOR	DRIVEABILITY		COST		RELIABILITY	MAINTAINABILITY	AVAILABILITY
								CRITICAL	GENERAL	INSTALLATION	RECURRING			
1972 FEDERAL TEST PROCEDURE (CVS)														
Retrofit Program Test Data (Up to 18 Tests for Each Device):														
1	1	Air Bleed to Intake Manifold	18	(3)	(6)	1	1	1	1	1	1	1	1	1
2	96	Catalytic Converter with Distributor Vacuum Advance Disconnect	17	0	(6)	1	1	1	1	0 COST LIMIT EXCEEDED	0 COST LIMIT EXCEEDED	1	1	1
3	175	Ignition Timing Modification with Lean Idle Adjustment	10	0	(6)	1	1	1	1	1	0 COST LIMIT EXCEEDED	1	1	1
4	246	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	15	0	(6)	1	1	1	1	0 COST LIMIT EXCEEDED	1	1	1	1
Retrofit Program Test Data (Up to 3 Tests for Each Device):														
5	10	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	2	(3)	(6)	1	1	1	1	1	1	1	1	1
6	33	Carburetor Modification, Main Jet Differential Pressure	2	0	(6)	0 NOx INCREASED	0 POTENTIAL FIRE HAZARD	1	1	1	1	1	1	1
7	42	Air Bleed to Intake Manifold	2	(3)	(6)	1	1	1	1	1	1	1	1	1
8	69	Electronic-Controlled Vac Advance Disconnect and Carburetor Lean Idle Mod	3	(3)	(6)	1	1	1	1	1	1	1	1	1
9	245	Variable Camshaft Timing	1	0	(6)	0 HC AND CO INCREASED	1	1	1	1	0 COST LIMIT EXCEEDED	1	1	1
10	288	Carburetor Main Discharge Nozzle Modification	2	0	(6)	0 NOx INCREASED	1	1	1	1	0 COST LIMIT EXCEEDED	1	1	1
11	295	Carburetor with Variable Venturi	1	0	(6)	0 HC INCREASED	1	1	0 POOR	1	0 COST LIMIT EXCEEDED	1	1	1
Developer and EPA Supplied Data:														
12	23	Electronic Ignition Unit	1	0	(6)	0 CO AND NOx INCREASED	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
13	24	Heavy Duty Positive Crankcase Control Valve with Air Bleed	(4)	(8)	(6)	1	(8)	(8)	(8)	1	1	1	1	1
14	52	LPG Conversion	18	0	(6)	1	(8)	(8)	(8)	0 COST LIMIT EXCEEDED	1	1	1	1
15	95	Ignition Spark Modification	1	0	(6)	0 HC, CO AND NOx INCREASED	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
16	100	Turbocharger	1	(8)	(6)	1	(8)	(8)	(5)	(8)	(8)	(8)	(8)	(8)
17	172	Intake Manifold Modification	1	0	(6)	0 HC INCREASED	1	(8)	(8)	1	1	1	1	1
18	292	Catalytic Converter	1	0	(6)	0 CO INCREASED	1	(8)	(8)	1	1	1	1	1
19	294	Exhaust Gas Recirculation with Carburetor Modification	1	0	(6)	0 HC INCREASED	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
20	418	Air Bleed to Intake Manifold	(10)	(8)	(6)	1	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
21	460	Compressed Natural Gas Dual-Fuel Conversion	1	0	(6)	0 CO, AND NOx INCREASED	(8)	(8)	(8)	0 COST LIMIT EXCEEDED	(8)	1	(8)	(8)
22	462	Air Bleed to Intake and Exhaust Manifolds	(11)	0	(6)	0 NOx INCREASED	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
23	465	Fuel Additive	1	(8)	(6)	1	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
24	466	LPG-Gasoline Dual-Fuel Conversion	6	(8)	(6)	1	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
No Baseline Given for the Following Devices: (6)														
25	93	Catalytic Conversion with Exhaust Gas Recirc, Spark Mod, and Lean Idle Mixture	6	(8)	(6)	(13)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
26	459	LPG Conversion with Deceleration Unit	1	(8)	(6)	(13)	(8)	(8)	(8)	0 COST LIMIT EXCEEDED	1	1	1	1
27	461	LPG Conversion with Exhaust Reactor Pulse Air Injection & Exh Gas Recirc	1	(8)	(6)	(13)	(8)	(8)	(8)	0 COST LIMIT EXCEEDED	(8)	(8)	1	(8)
28	463	Rich Thermal Reactor with Exhaust Gas Recirculation and Spark Retard	3	(8)	(6)	(13)	(8)	(8)	(8)	(8)	(8)	(8)	1	(8)
29	464	Methanol Fuel Conversion with Catalytic Converter	6	(8)	(6)	(13)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
30	468	Lean Thermal Reactor with Exhaust Gas Recirculation	5	(8)	(6)	(13)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)

Table 5-1. CRITERIA INDEX RESULTS FOR DEVICES EVALUATED IN RETROFIT PROGRAM (CONT)

ITEM	DEVICE NO.	DESCRIPTION	NO. OF TESTS	CRITERIA INDEX	CRITERIA INDEX FACTORS (1)(2)									
					EMISSIONS STANDARD	EMISSION BASELINE	SAFETY FACTOR	DRIVEABILITY		COST		RELIABILITY	MAINTAINABILITY	AVAILABILITY
								CRITICAL	GENERAL	INSTALLATION	RECURRING			
EPA-9X7CVS (7)														
1	469	Rich Thermal Reactor with Exhaust Gas Recirculation and Particulate Control	2	(8)	(6)	1	(8)	(8)	(8)	0 COST LIMIT EXCEEDED	(8)	(8)	(8)	(8)
7-CYCLE 7-MODE COLD START														
Developer and EPA Supplied Data:														
1	36	Fuel Conditioning by Exposure to Electromagnetic Field	(14)	0	0 HC & CO EXCEEDS STD	0 HC INCREASED	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
2	57	Air Bleed with Exhaust Gas Recirc and Vacuum Advance Disconnect	1	0	0 HC EXCEEDS STD	1	0 POTENTIAL FIRE HAZARD	1	1	1	1	1	1	1
3	59	Three-Stage Exhaust Gas Control System	1	0	0 HC & CO EXCEEDS STD	1	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
4	62	Catalytic Converter	1	0	0 CO EXCEEDS STD	1	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
5	164	Exhaust Gas Filter	1	0	0 NOx EXCEEDS STD	1	(8)	(8)	(8)	0 COST LIMIT EXCEEDED	1	(8)	(8)	(8)
6	182	Fuel and Oil Additives	(15)	0	(12)	1	1	(8)	(8)	1	0 COST LIMIT EXCEEDED	(8)	1	(8)
7	244	Rich Thermal Reactor	(18)	0	(12)	(5)	1	(8)	(8)	0 COST LIMIT EXCEEDED	1	1	1	1
8	315	Closed Blowby Control System	1	0	(6)	(13)	0 POSSIBLE WOT	(8)	(8)	1	1	1	1	1
9	317	Carburetor Modification with Vacuum Advance Disconnect	3	0	0 CO EXCEEDS STD	1	0 POTENTIAL FIRE HAZARD	1	1	1	1	1	1	1
10	322	Exhaust Gas Backpressure Valve	1	0	0 HC & CO EXCEEDS STD	0 HC AND NOx INCREASED	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
11	384	Air-Fuel Mixture Diffuser	1	0	0 CO EXCEEDS STD	0 CO INCREASED	(8)	(8)	(8)	(8)	(8)	1	1	(8)
12	401	Air-Vapor Bleed to Intake Manifold	1	0	0 NO_x EXCEEDS STD	0 NOx INCREASED	1	(8)	(8)	1	0 COST LIMIT EXCEEDED	1	0 LOW MMBM	0 LOW AVAILABILITY
13	425	Exhaust Gas Afterburner	1 (16)	0	(5)	(5)	0 EXPLOSION HAZARD	(8)	(8)	0 COST LIMIT EXCEEDED	1	1	1	1
14	430	Induction Modification	2	0	0 CO EXCEEDS STD	1	1			1	1	1	1	1
15	458	Air Bleed to Intake Manifold	(17)	0	0 NOx EXCEEDS STD	1	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
No Baseline Given for the Following Devices:														
16	22	Electronic Fuel Injection	1	(8)	1	(13)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)
17	31	Thermal Reaction by Turbine Blower Air Injection	6	0	(5)	(13)	1	(8)	(8)	0 COST LIMIT EXCEEDED	1	1	1	1
18	56	Crankcase Blowby and Idle Air Bleed Modification	3	0	0 HC & NOx EXCEEDS STD	(13)	0 POTENTIAL FIRE HAZARD	(8)	(8)	1	1	1	1	1
19	160	Closed or Open Blowby Control System with Filter	1	(8)	1	(13)	1	(8)	(8)	1	1	1	1	1
7-MODE HOT START														
7-Cycle 7-Mode Hot Start Test:														
1	170	Closed Blowby Control System	1	0	(6)	0 CO INCREASED		(8)	(8)	1	1	1	1	1
2	279	Fuel Conditioner	1	0	(6)	1	0 POTENTIAL FIRE HAZARD	(8)	(8)	1	1	1	1	1
3	296	Ignition Timing and Spark Modification	1	(3)	(6)	1	1	(8)	(8)	1	1	1	1	1
4	325	Air-Vapor Bleed to Intake Manifold	7	0	(6)	1	1	(8)	(8)	1	0 COST LIMIT EXCEEDED	1	0 LOW MMBM	0 LOW AVAILABILITY
5	427	Closed or Open Blowby Control System with Filter	2	(3)	(6)	1	1	(8)	(8)	1	0 COST LIMIT EXCEEDED	1	1	1
6	433	Air-Vapor Bleed to Intake Manifold	7	0	(6)	1	1	(8)	(8)	1	0 COST LIMIT EXCEEDED	1	0 LOW MMBM	0 LOW AVAILABILITY
No Baseline Given for the Following Device:														
7	165	Exhaust Gas Afterburner/ Recirculation with Blowby and Fuel Evap Recirc	1	0	(6)	(13)	0 EXPLOSION HAZARD	(8)	(8)	0 COST LIMIT EXCEEDED	1	1	1	1
STEADY STATE														
Steady State Test:														
1	308	Exhaust Gas Afterburner	(9)	0	(6)	0 HC INCREASED	1	(8)	(8)	1	1	1	1	1
2	457	Water Injection	(9)	(8)	(6)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)

Table 5-1. CRITERIA INDEX RESULTS FOR DEVICES EVALUATED IN RETROFIT PROGRAM (CONCL)

ITEM	DEVICE NO.	DESCRIPTION	NO. OF TESTS	CRITERIA INDEX	CRITERIA INDEX FACTORS(1)(2)									
								DRIVEABILITY		COST				
					EMISSIONS STANDARD	EMISSION BASELINE	SAFETY FACTOR	CRITICAL	GENERAL	INSTALLATION	RECURRING	RELIABILITY	MAINTAINABILITY	AVAILABILITY
UNKNOWN														
No Emission Data Provided by the Developer for the Following Devices:														
1	259	Photocell-Controlled Ignition System	(19)	(8)	(8)	(8)	1	(8)	(8)	1	1	1	1	1
2	268	Capacitive Discharge Ignition	(18)	(8)	(8)	(8)	1	(8)	(8)	1	1	1	1	1
3	282	LP Gas Injection	(18)	0	(8)	(8)	1	(8)	(8)	0 COST LIMIT EXCEEDED	1	1	1	1
4	408	Exhaust Gas and Blowby Recirc with Intake Vac Control and Turbulent Mixing	(19)	0	(8)	(8)	0 EXPLOSION HAZARD	(8)	(8)	1	1	1	1	1
5	440	Air-Fuel Mixture Deflection Plate	(18)	(8)	(8)	(8)	1	(8)	(8)	1	1	1	1	1
No Emission Evaluation was Made on the Following Device:														
6	467	Fuel Evaporation Control System	(19)	0	(8)	(8)	(8)	(8)	(8)	0 COST LIMIT EXCEEDED	(8)	(8)	1	(8)

(1) A criteria index factor of one (1) means that the device passed the evaluation criteria. A zero (0) indicates failure to pass the criteria.
(2) Performance analysis results are presented in Section 6.
(3) Criteria Index cannot be established because emission standard not set. (See Paragraph 5.1 for explanation.)
(4) 6 baseline and 5 device tests for HC and CO; 3 baseline and 4 device tests for NOx.
(5) No NOx values reported.
(6) No standards set for emission test procedure used, therefore, emission standard criterion factor unknown.
(7) EPA Interim 9-Cycle. 7-Mode CVS Emission Test Procedure (refer to Volume II, Reference 16).
(8) Insufficient data on which to base CI evaluation.
(9) Different steady state speeds.
(10) 16 baseline tests and 11 device tests on 3 cars.
(11) 10 baseline and 9 device tests for HC and CO, and 6 baseline and 6 device tests for NOx, on 2 cars.
(12) Emission levels not reported. Percentage reduction only.
(13) No baseline data reported.
(14) 1 baseline and 11 device tests for HC and CO only.
(15) 4 tests for HC and CO; 1 test for NOx.
(16) HC and CO measured only.
(17) 1 baseline and 2 device tests on 1 vehicle.
(18) Unknown.
(19) No test data.

satisfied the evaluation criterion for that particular performance parameter. A value of 0 indicates that the device did not meet the evaluation criterion for that performance parameter.

As noted in Section 3, if a device fails even one of the evaluation criterion, its overall Criteria Index is 0. In many cases, the data obtained from the development sources were not complete enough to evaluate a device against all criteria. In these cases, the Criteria Index could be established only if the device failed one of the criteria for which there were sufficient data. Devices tested by the 1972 Federal Test Procedure (including those in the retrofit test program) did not receive an emission standard rating, and therefore a Criteria Index could not be established for these devices unless they failed one of the other criteria.

Table 5-1 also identifies the cause of a device failing the various Criteria Index factors. For the systems tested in the retrofit program, Devices 33, 245, 288, and 295 indicated an increase in emissions over their baseline values, even beyond the allowable 10 percent experimental error. A requirement for a retrofit device to be considered feasible in this program was that it not increase any pollutant, even though it was not designed to control that pollutant. Among the devices evaluated on the basis of supplied emissions data, there were 13 that indicated noncompliance with this criterion. Among the 19 devices that could be evaluated against the emission standards criterion, 12 failed.

Nine devices were considered to be potentially hazardous and were therefore given a safety factor of zero. These potential hazards are outlined in the Volume II description of these devices. Another failing factor in the Criteria Index was critical driveability due to vehicle stalling on cold acceleration. Several baseline driveability tests also displayed this stall condition, but it was worse with the device installed. In these cases the fault may not be entirely attributable to the device.

For the systems tested in the retrofit program, Devices 96 and 246 exceeded the assumed cost limit criterion of $85.00 for an installed device. Another failing factor in the group of devices tested in the retrofit program was the recurring cost. This was due to the average loss in fuel economy with the device installed and caused the recurring cost criterion of $0.125/100 miles to be exceeded.

In the retrofit developer data group, driveability data were incomplete and therefore critical and general driveability ratings could not be made. Cost data supplied by the developers were generally good. Reliability and maintainability data were generated for the most part by means of the engineering analysis described in Volume II.

All of the devices for which sufficient data were obtained or developed met the reliability criterion, and all but three met the maintainability criterion. Three devices failed to meet the availability criterion, and 16 failed either the installation or recurring cost criteria.

5.3 RETROFIT SYSTEM FEASIBILITY

The feasibility and infeasibility of a retrofit device, within the context of this study, can only be determined with respect to the device's applicability for use as a retrofit method for controlling used car emissions. A device may be rated infeasible, without infringing upon its use for other performance applications. For example, some devices, while being claimed as emission reduction devices, may actually be devices for enhancing some engine performance parameter that only indirectly or insignificantly reduces emissions. The evaluator should be careful in distinguishing retrofit emission control devices from performance devices, since the latter may cause an emission increase. Any additional claims made for a device beyond those concerning emissions were not contested, since the findings of this study pertain only to a device's use as a retrofit method to control vehicle emissions effectively without unacceptable vehicle performance or cost penalties.

To determine which devices are feasible and which are infeasible, the evaluation criteria presented in Table 3-1 can be applied as is or as modified to suit the evaluator's requirements. In effect, the evaluation criteria determine the feasibility or infeasibility of a device. Those devices that passed the evaluation criteria levels would be the feasible retrofit systems and the rest may be infeasible to some degree.

It should be noted that most of the devices evaluated in this study are in the prototype stage of development. Refinements in device design through careful engineering and manufacturing may eliminate the reasons for considering a device infeasible.

SECTION 6

PERFORMANCE INDEX ANALYSIS

As previously defined in Section 3, the Performance Index (PI) is made up of the Emission Index (EI), the Driveability Index (DI), and the Cost Index (CI) with units of per unit reduction, points, and dollars per 100 miles, respectively (refer to Eq. 3.2):

The Performance Index equation is:

$$PI = \frac{C_1(EI) - C_2(DI) - C_3(CI)}{C_1 + C_2 + C_3} \tag{6.1}$$

Where C_1, C_2, and C_3 are the weighting coefficients.

The Emission Index presents an emission reduction benefit while the Driveability and Cost Indexes represent penalties, hence the minus signs.

This section presents the test results of the Emission Index, Driveability Index, and Cost Index separately. These results were then combined to establish the overall Performance Index. Also presented are the emission reduction confidence intervals and the sensitivity analysis of the Driveability and Cost Indexes.

6.1 EMISSION REDUCTION RESULTS

The statistical confidence and dispersion of the emission reduction test data and the results of the Emission Index are presented in the following paragraphs.

Emission levels were determined for the vehicle without the device ("baseline") and with the device installed ("retrofit"). One way to make device performance comparisons in several different cars is to examine the emission level reductions between baseline and retrofit tests for the same car. The measure of the effectiveness of a retrofit device is the percentage reduction from baseline:

$$\text{Percentage Reduction} = \frac{\text{Baseline Emissions - Retrofit Emissions}}{\text{Baseline Emissions}} \times 100$$

This method tends to eliminate the inherent car-to-car variability and the possible influence of the baseline test-to-test variability when installing and removing devices. This is a particularly appropriate comparison method for the retrofit program because the number of comparisons per device was relatively small (up to 18 tests per device).

Table 6-1 lists the percentage emission reduction of the devices tested in the retrofit program, whereas Table 6-2 lists the emission reduction data provided by the retrofit developers and the Environmental Protection Agency. Appendices F and G present the absolute baseline and retrofit emission results.

A statistical treatment of the emission reduction data was conducted on the following four devices tested in the retrofit program:

Device 1: Air Bleed to Intake Manifold

Device 96: Catalytic Converter with Distributor Vacuum Advance Disconnect

Device 175: Ignition Timing Modification with Lean Idle Adjustment

Device 246: Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect

These four devices are described in detail in Volume II. In some cases a replicate test was run with the same device; these are labeled "Test 2" in Table 6-1. No statistical analysis was conducted on the other devices listed in Table 6-1. The emission reduction data for Devices 1, 96, 175, and 246 presented in Table 6-1 were plotted on probability paper. The purpose of these plots was to determine any large departures from normality of the retrofit emission reduction results. The plots showed some evidence that the device performance on the test vehicles may have been close to a normal population. Discontinuities indicated that more than one population was being sampled (that is, all of the devices of one developer tested may not have been performing in the same way).

The extreme discontinuities in the probability plots suggested that some of the emission reduction data might have been "outliers." The input baseline and retrofit emission data were carefully reviewed for test anomalies and computer input errors. If no anomalies were apparent, the Dixon test was then applied to determine whether the outlier data point could be excluded from further analysis on a statistical basis (see paragraph 4.2.1.4 for discussion of the Dixon tests).

Two kinds of statistical testing were carried out on the emission reduction data of devices tested in the retrofit program. One statistical test determined whether the Test 1 and Test 2 results could be combined, and then, in turn, if the results of the two cities could be combined. This was accomplished using the Welch approximation for the Fisher-Behrens problem (Reference 13). The Fisher-Behrens problem is the testing of the hypothesis that the means of two normal populations are equal regardless of the size of their respective variances based on two samples, one drawn from each population. At the time of this study the best way to test this hypothesis was believed to be Welch's approximate t solution (Reference 8). A brief description and a sample calculation of Welch's approximate t solution of the Fisher-Behrens problem is presented in Appendix H.

Table 6-1. PERCENTAGE EMISSION REDUCTION OF DEVICES TESTED IN RETROFIT PROGRAM

CAR NO. AND LOCATION(1)	MAKE AND CID	TEST 1			TEST 2		
		HC	CO	NO_x	HC	CO	NO_x
Device 1: Air Bleed to Intake Manifold							
Anaheim							
1	65 Chev 194	17.7	-6.3	-50.5	(2)		
2	65 Ford 289	30.5	31.4	-10.6			
3	65 Ply 318	-8.2	60.6	16.6			
4	65 Chev 327	4.8	46.4	14.6			
5	65 Ford 390	20.8	41.4	0.0			
6	61 Chev 283	(3)	36.1	12.7			
17	65 Ford 390						
18	61 Chev 283						
19	65 VW 92	46.4	56.9	12.4			
Taylor							
8	65 Ford 289	41.0	89.3	24.9	3.1	77.9	-17.4
9	65 Ply 318	26.5	79.3	13.9	6.9	34.7	24.8
10	65 Chev 327	-29.0	93.1	-0.3	2.8	73.1	-18.8
11	65 Ford 390	23.6	74.0	-28.4	51.0	63.2	-57.5
12	61 Chev 283	46.0	50.4	3.6	1.9	52.6	-33.1
16	65 Chev 327						
20	65 VW 92	71.2	85.5	6.9			
Device 96: Catalytic Converter with Vacuum Advance Disconnect							
Anaheim							
1	65 Chev 194	85.1(4)	78.3	76.7	51.6(4)	77.4	15.7
2	65 Ford 289	92.2(4)	95.1	65.0	75.6(4)	63.2	41.1
3	65 Ply 318	34.1	12.1	68.8	65.9(4)	51.2	30.2
4	65 Chev 327	86.7(4)	99.2	38.0	75.1(4)	76.6	56.6
5	65 Ford 390	40.6	24.1	66.3	38.4	26.9	28.1
6	61 Chev 283	68.1(4)	32.9	34.6	48.7	4.1	11.6
Taylor							
8	65 Ford 289	66.6	67.4	51.7			
9	65 Ply 318	85.3	83.2	58.1			
10	65 Chev 327	70.8	77.6	61.7			
11	65 Ford 390	92.9(4)	99.5	57.6			
12	61 Chev 283	86.2(4)	95.8	50.0			
Device 246: Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect							
Anaheim							
1	65 Chev 194	(3)	12.4	60.0			
2	65 Ford 289	27.6	33.7	37.4			
3	65 Ply 318	-13.7	32.9	54.5			
4	65 Chev 327	2.8	23.4	36.9			
17	65 Ford 390	0.9	10.3	58.5			
18	61 Chev 283	(3)	-8.3	44.5			
19	65 VW 92	15.4	11.6	26.1			

Table 6-1. PERCENTAGE EMISSION REDUCTION OF DEVICES TESTED IN RETROFIT PROGRAM (CONT)

CAR NO. AND LOCATION(1)	MAKE AND CID	TEST 1			TEST 2		
		HC	CO	NO_x	HC	CO	NO_x
Taylor							
8	65 Ford 289	(3)	(3)	(3)	-11.1	-4.2	57.7
9	65 Ply 318	8.3	58.4	47.6	-5.0	60.8	58.1
10	65 Chev 327	(3)	(3)	(3)	18.3	45.4	55.8
11	65 Ford 390	18.0	31.4	44.7	46.0	72.8	49.3
12	61 Chev 283	9.9	30.1	40.9	40.2	53.4	41.4
20	65 VW 92	9.4	-26.6	(3)			
Device 175: Ignition Timing Modification with Lean Idle Adjustment							
Anaheim							
1	65 Chev 194	14.1	11.4	43.6			
3	65 Ply 318	33.1	21.5	43.0			
4	65 Chev 327	4.8	8.1	14.9			
5	65 Ford 390	-21.0	-9.8	35.2			
6	61 Chev 283	(3)	(3)	(3)			
Taylor							
8	65 Ford 289	16.8	76.5	56.6			
9	65 Ply 318	26.5	78.7	42.5			
10	65 Chev 327	19.0	61.1	56.5			
11	65 Ford 390	24.5	74.7	3.0			
12	61 Chev 283	33.7	67.0	34.4			
16	65 Chev 327	40.0	73.4	42.8			
Device 10: Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect							
Anaheim							
4	65 Chev 327	45.9	39.0	55.5			
6	61 Chev 283	27.5	18.3	51.6			
Device 33: Carburetor Main Jet Differential Pressure Modification							
2	65 Ford 289	52.7	62.8	-121.6			
4	65 Chev 327	13.0	28.7	34.9			
Device 42: Air Bleed to Intake Manifold							
4	65 Chev 327	-7.6	50.0	-3.1			
5	65 Ford 390	54.0	40.9	8.3			

Table 6-1. PERCENTAGE EMISSION REDUCTION OF DEVICES TESTED IN RETROFIT PROGRAM (CONCL)

CAR NO. AND LOCATION(1)	MAKE AND CID	TEST 1			TEST 2		
		HC	CO	NO_x	HC	CO	NO_x
Device 69: Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification							
Anaheim							
3	65 Ply 318	39.2	30.1	32.1			
4	65 Chev 327	27.5	37.6	-5.6			
5	65 Ford 390	30.6	20.0	46.7			
Device 245: Variable Camshaft Timing							
6	61 Chev 283	-35.9	-26.9	20.9			
Device 288: Carburetor Main Discharge Nozzle Modification							
2	65 Ford 289	6.2	38.9	-1.8			
6	61 Chev 283	2.0	34.8	-35.6			
Device 295: Carburetor with Variable Venturi							
5	65 Ford 390	-36.9	20.0	25.4			

(1) Positive percentage denotes emission reduction from baseline and negative percentage denotes emission increase from baseline.
(2) All blank spaces and columns denote that no tests were performed, except for Note (3).
(3) Measured test data were invalid.
(4) Air pump installed and operating.

The second statistical test considered whether the percentage emission reduction was different than zero, for a Test 1, a Test 2 or a test location data combination. These tests used the normal-theory student t test. Neyman-type 90 percent confidence limits were calculated for the mean percentage emission reduction.

In analyzing t test results, it must be pointed out that statistical tests have poor "discriminatory power" for small samples. For a "90 percent t test," there is a 10 percent chance of stating that there is a significant emission reduction when it is really zero.

This kind of error is the Type I error, and can be controlled by choosing a value as the error for the test; here 10 percent. However, once this value is chosen, the chance of making a second kind of mistake has been fixed. This is the Type II error, which states that there is no significant emission reduction when the device is actually doing some good. The magnitude of the Type II error depends on the size of the real percentage emission reduction and on the sample size. If the real percentage reduction is only slightly different than zero, the chance of

Table 6-2. AVERAGE PERCENTAGE EXHAUST EMISSION REDUCTION BY TEST PROCEDURE FOR DEVICES EVALUATED IN RETROFIT PROGRAM

NOTE: THE RELIABILITY OF THE DATA SHOWN DEPENDS ON THE TYPE OF TEST PROCEDURE AND NUMBER OF TESTS.

TEST TYPE	ITEM	DEVICE	DESCRIPTION	DATA SOURCE(3)	NO. OF TESTS	AVERAGE PERCENTAGE EMISSION REDUCTION(1)			FUEL CONSUMPTION PERCENTAGE CHANGE(2)
						HC	CO	NO_x	
1972 FEDERAL TEST PROCEDURE (CVS)	Retrofit Program Test Data (Up to 15 Tests for Each Device):								
	1	1	Air Bleed to Intake Manifold	R	18	21.0	57.8	-4.8	4
	2	96	Catalytic Converter with Distributor Vacuum Advance Disconnect	R	17	68.4	62.6	47.8	-1
	3	175	Ignition Timing Modification with Lean Idle Adjustment	R	10	19.2	46.3	37.2	-10
	4	246	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	R	15	12.1	30.9	47.6	7
	Retrofit Program Test Data (Up to 3 Tests for Each Device):								
	5	10	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	R	2	36.7	28.7	53.6	0.5
	6	33	Carburetor Modification, Main Jet Differential Pressure	R	2	32.9	45.8	-43.4	13
	7	42	Air Bleed to Intake Manifold	R	2	23.2	45.3	2.6	7
	8	69	Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification	R	3	32.4	29.2	24.4	0
	9	245	Variable Camshaft Timing	R	1	-35.9	-26.9	20.9	-10
	10	288	Carburetor Main Discharge Nozzle Modification	R	2	4.1	36.9	-18.7	-6
	11	295	Carburetor with Variable Venturi	R	1	-36.9	20.0	25.4	-10
	Developer and EPA Supplied Data:								
	12	23	Electronic Ignition Unit	E	1	2.9	-16.3	-56.0	No data available
	13	24	Heavy Duty Positive Crankcase Control Valve with Air Bleed	E	(4)	3.9	12.6	7.4	
	14	52	LPG Conversion	E	18	81.1	85.2	64.9	↑
	15	95	Ignition Spark Modification	E	1	-26.7	-17.4	-31.3	
	16	100	Turbocharger	E	1	14.0	12.0	8.0	
	17	172	Intake Manifold Modification	E	1	-15.0	0.0	27.0	
	18	292	Catalytic Converter	E	1	21.2	-15.4	41.0	
	19	294	Exhaust Gas Recirculation with Carburetor Modification	E	1	-78.9	10.4	30.0	
	20	418	Air Bleed to Intake Manifold	E	(5)	8.2	39.4	1.9	
	21	460	Compressed Natural Gas Dual-Fuel Conversion	E	1	0.0	-19.0	-64.0	
	22	462	Air Bleed to Intake and Exhaust Manifolds	E	(6)	24.6	12.6	-30.0	
	23	465	Fuel Additive	E	1	12.3	9.9	8.2	
	24	466	LPG-Gasoline Dual-Fuel Conversion		6	19.0	70.0	29.0	
	No Baseline Given for the Following Devices: (12)								
	25	93	Catalytic Converter with Exhaust Gas Recirculation, Spark Modification, and Lean Idle Mixture	E	6	(7)	(7)	(7)	
	26	459	LPG Conversion with Deceleration Unit	E	1	(7)	(7)	(7)	
	27	461	LPG Conversion with Exhaust Reactor Pulse Air Injection and Exhaust Gas Recirculation	E	1	(7)	(7)	(7)	
	28	463	Rich Thermal Reactor with Exhaust Gas Recirculation and Spark Retard	E	3	(7)	(7)	(7)	
	29	464	Methanol Fuel Conversion with Catalytic Converter	E	6	(7)	(7)	(7)	
	30	468	Lean Thermal Reactor with Exhaust Gas Recirculation	D	5	(7)	(7)	(7)	
EPA-9X7/CVS (14)	1	469	Rich Thermal Reactor with Exhaust Gas Recirculation and Particulate Control	E	2	80.0	44.0	65.0	↓ No data available

Table 6-2. AVERAGE PERCENTAGE EXHAUST EMISSION REDUCTION BY TEST PROCEDURE FOR DEVICES EVALUATED IN RETROFIT PROGRAM (CONCL)

NOTE: THE RELIABILITY OF THE DATA SHOWN DEPENDS ON THE TYPE OF TEST PROCEDURE AND NUMBER OF TESTS.

TEST TYPE	ITEM	DEVICE	DESCRIPTION	DATA SOURCE(3)	NO. OF TESTS	AVERAGE PERCENTAGE EMISSION REDUCTION(1) HC	CO	NO_x	FUEL CONSUMPTION PERCENTAGE CHANGE(2)
7-CYCLE 7-MODE COLD START	7-Cycle 7-Mode Cold Start Test Procedure:								
	1	36	Fuel Conditioning by Exposure to Electromagnetic Field	E	(8)	-12.5	-0.4	(7)	No data available
	2	57	Air Bleed with Exhaust Gas Recirculation and Vacuum Advance Disconnect	D	1	55.8	52.3	46.6	
	3	59	Three-Stage Exhaust Gas Control System	D	1	32.0	18.3	11.0	
	4	62	Catalytic Converter	E	1	44.0	14.5	7.0	
	5	164	Exhaust Gas Filter	D	1	10.0	2.0	0.1	
	6	182	Fuel and Oil Additives	D	(9)	26.2	30.5	24.0	
	7	244	Rich Thermal Reactor	D	(7)	83.0	67.0	(7)	
	8	315	Closed Blowby Control System	D	1	28.3	28.0	(7)	
	9	317	Carb Mod with Vac Adv Disconnect	D	3	32.0	22.0	35.0	
	10	322	Exhaust Gas Backpressure Valve	E	1	-71.3	6.9	-13.0	
	11	384	Air-Fuel Mixture Diffuser	D	1	40.2	19.6	29.4	
	12	401	Air-Vapor Bleed to Intake Manifold	D	1	25.0	34.1	-31.0	
	13	425	Exhaust Gas Afterburner	D	1(10)	97.0	97.0	(7)	
	14	430	Induction Modification	D	2	34.0	9.5	36.5	
	5	458	Air Bleed to Intake Manifold	E	(11)	-3.7	7.0	-8.1	
	No Baseline Given for the Following Devices: (12)								
	16	22	Electronic Fuel Injection	E	1	(7)	(7)	(7)	
	17	31	Thermal Reaction by Turbine Blower Air Injection	D	6	(7)	(7)	(7)	
	18	56	Crankcase Blowby and Idle Air Bleed Mod	D	3	(7)	(7)	(7)	
	19	160	Closed or Open Blowby Control System with Filter	D	1	(7)	(7)	(7)	
7-MODE HOT START	7-Cycle 7-Mode Hot Start Test:								
	1	170	Closed Blowby Control System	D	1	10.0	-31.0	47.0	
	2	279	Fuel Conditioner	D	1	3.4	24.5	4.3	
	3	296	Ignition Timing and Spark Modification	D	1	8.0	4.0	-4.0	
	4	325	Air-Vapor Bleed to Intake Manifold	D	7	29.7	32.1	10.0	
	5	427	Closed or Open Blowby Control System with Filter	D	2	5.5	48.6	0.5	
	6	433	Air-Vapor Bleed to Intake Manifold	D	7	29.7	32.1	10.0	
	No Baseline Given for the Following Device: (12)								
	7	165	Exhaust Gas Afterburner/Recirculation with Blowby and Fuel Evaporation Recirculation	D	1	(7)	(7)	(7)	
STEADY STATE	Steady State								
	1	308	Exhaust Gas Afterburner	D	3(13)	-17.0	-6.3	9.0	
	2	457	Water Injection	E	(13)	0.0	0.0	75(15)	
UNKNOWN	No Emission Data Provided by the Developer for the Following Devices:								
	1	259	Photocell-Controlled Ignition System	D	(7)	(7)	(7)	(7)	
	2	268	Capacitive Discharge Ignition	D	(7)	(7)	(7)	(7)	
	3	282	LP Gas Injection	D	(7)	(7)	(7)	(7)	
	4	408	Exhaust Gas and Blowby Recirculation with Intake Vacuum Control and Turbulent Mixing	D	(7)	(7)	(7)	(7)	
	5	440	Air-Fuel Mixture Deflection Plate	D	(7)	(7)	(7)	(7)	
	No Emission Evaluation was Made on the Following Device:								
	6	467	Fuel Evaporation Control System	(7)	(7)	(7)	(7)	(7)	No data available

(1) Negative signs indicate an emission increase.

(2) Measured during 1972 Federal Test Procedure for exhaust emissions. Negative signs indicate less miles per gallon.

(3) Data Source:
R = Retrofit Test Program
D = Developer Supplied Data
E = Environmental Protection Agency

(4) 6 baseline and 5 device tests for HC and CO; 3 baseline and 4 device tests for NOx.

(5) 16 baseline tests and 11 device tests on 3 cars.

(6) 10 baseline and 9 device tests for HC and CO, and 6 baseline and 6 device tests for NOx, on 2 cars.

(7) Unknown.

(8) 1 baseline and 11 device tests for HC and CO only.

(9) 4 tests for HC and CO; 1 test for NOx.

(10) HC and CO measured only.

(11) 1 baseline and 2 device tests on 1 car.

(12) See Volume II for emission levels with devices installed.

(13) Different steady state speeds.

(14) EPA Interim 9-Cycle, 7-Mode CVS Emission Test Procedure (refer to Volume II, Reference 16).

(15) NOx reduction reported for water-to-fuel ratio of 0.9:1. No appreciable effect reported for HC or CO.

Table 6-3. DISCRIMINATORY POWER OF t TESTS (REFERENCE 10) (1)

Percentage Emission Reduction	Number of Tests	Chance of Type II Error, Percent	"Discriminatory Power" of Test, Percent
10	6	70	30
	10	51	49
	20	29	71
20	6	27	73
	10	4	96
	20	0.5	99.5
40	6	2	98

(1) Type I error set at 10 percent. Population standard deviation of individual percentage emission reductions assumed to be 20 percent for this example.

making a Type II error is 90 percent (100 - 10). However, for larger percentage emission reductions, say 10 percent and a sample size of 6, the chance of making a Type II error drops to 70 percent. At 40 percent emission reduction, the chance becomes very small (about 2 percent) for making a Type II error. Calculated examples of discriminatory power of the t tests are shown in Table 6-3.

Table 6-4 presents the mean percentage emission reductions and the 90 percent confidence limits for the various test data combinations for Devices 1, 96, 175, and 246. The test data combinations were statistically determined by Welch's approximate t solution.

An interpretation of the test data combinations follows for Device 1. On the basis of the Welch tests, the HC and NOx test data for Anaheim, Taylor Test 1, and Taylor Test 2, were statistically combined to form the largest possible sample size. For Device 1, the Welch test did not allow the CO reduction data between Anaheim and Taylor to be statistically combined, but did allow the Taylor 1 and Taylor 2 CO test data to be combined.

Figure 6-1 depicts the mean percentage emission reduction data and the 90 percent confidence limits from Table 6-4.

6.1.1 Device 1: Air Bleed to Intake Manifold

The Welch test allowed all HC and NOx test data to be statistically combined for analysis. However, the Welch test would not allow the Anaheim and Taylor CO data to be statistically combined. The general conclusions for this device are:

		90 Percent Confidence Intervals
HC	significant reduction	10 to 32 percent
CO	significant reduction	22 to 80 percent
NOx	insignificant increase	-15 to +5 percent

Table 6-4. MEAN PERCENTAGE EMISSION REDUCTION AND 90 PERCENT CONFIDENCE INTERVALS FOR EXHAUST EMISSION CONTROL RETROFIT SYSTEMS TESTED AT ANAHEIM, CALIFORNIA, AND TAYLOR, MICHIGAN(1)(2)

Hydrocarbon Reduction (%)			Carbon Monoxide Reduction (%)			Oxides of Nitrogen Reduction (%)		
Test Data(3) Combination	Mean (n)	90% Confidence Limits	Test Data(3) Combination	Mean (n)	90% Confidence Limits	Test Data(3) Combination	Mean (n)	90% Confidence Limits
Device 1: AIR BLEED TO INTAKE MANIFOLD								
$A_1+T_1+T_2$	21.0(17)	10.4 to 31.6	A_1	38.1(7)	21.8 to 54.4	$A_1+T_1+T_2$	-4.8(18)	-14.9 to 5.4
			T_1+T_2	70.3(11)	60.4 to 80.2			
Device 96: CATALYTIC CONVERTER WITH VACUUM ADVANCE DISCONNECT								
A_1+A_2	63.5(12)	53.0 to 74.0	A_1+A_2	53.4(12)	36.5 to 70.4	A_1+T_1	57.1(11)	50.2 to 64.1
T_1	80.4(5)	69.7 to 91.0	T_1	84.7(5)	72.1 to 97.3	A_2	30.6(6)	16.9 to 44.2
Device 175: IGNITION TIMING MODIFICATION WITH LEAN IDLE ADJUSTMENT								
A_1+T_1	19.2(10)	8.9 to 29.3	A_1	7.8(4)	-7.6 to 23.1	A_1+T_1	37.3(10)	27.5 to 47.0
			T_1	71.9(6)	66.5 to 77.3			
Device 246: SPEED-CONTROLLED EXHAUST GAS RECIRCULATION AND VACUUM ADVANCE DISCONNECT								
$A_1+T_1+T_2$	12.1(13)	3.1 to 21.1	T_1+T_2	43.5(8)	27.3 to 59.7	$A_1+T_1+T_2$	47.6(15)	43.1 to 52.1
			A_1	16.6(7)	5.7 to 27.4			

(1) Negative reductions indicate an emission level increase from baseline

(2) Confidence intervals calculated from data presented in Table 6-1

(3) A_1 = Anaheim Test 1 T_1 = Taylor Test 1
A_2 = Anaheim Test 2 T_2 = Taylor Test 2

(4) $A_1+T_1+T_2$ means that Anaheim Test 1, Taylor Tests 1 and 2 reduction data were combined as a single sample. See Appendix H for explanation of test data combinations as determined by Welch's approximate t solution of the Fisher-Behren problem. (X) indicates total number of tests.

Device 1, an air-bleed-to-intake-manifold type, demonstrated that it controls carbon monoxide and hydrocarbons. On some installations this system may increase the NOx emission levels due to the availability of excess oxygen.

6.1.2 Device 96: Catalytic Converter with Vacuum Advance Disconnect

The Welch test allowed the Anaheim Test 1 and Test 2 data to be combined for the HC and CO reduction but did not allow the data to be statistically combined for Anaheim and Taylor. The Welch test did allow the Anaheim Test 1 and Taylor Test 1 NOx test data to be combined.

The data clearly indicate that the catalytic converter with vacuum advance disconnect controls all three effluents.

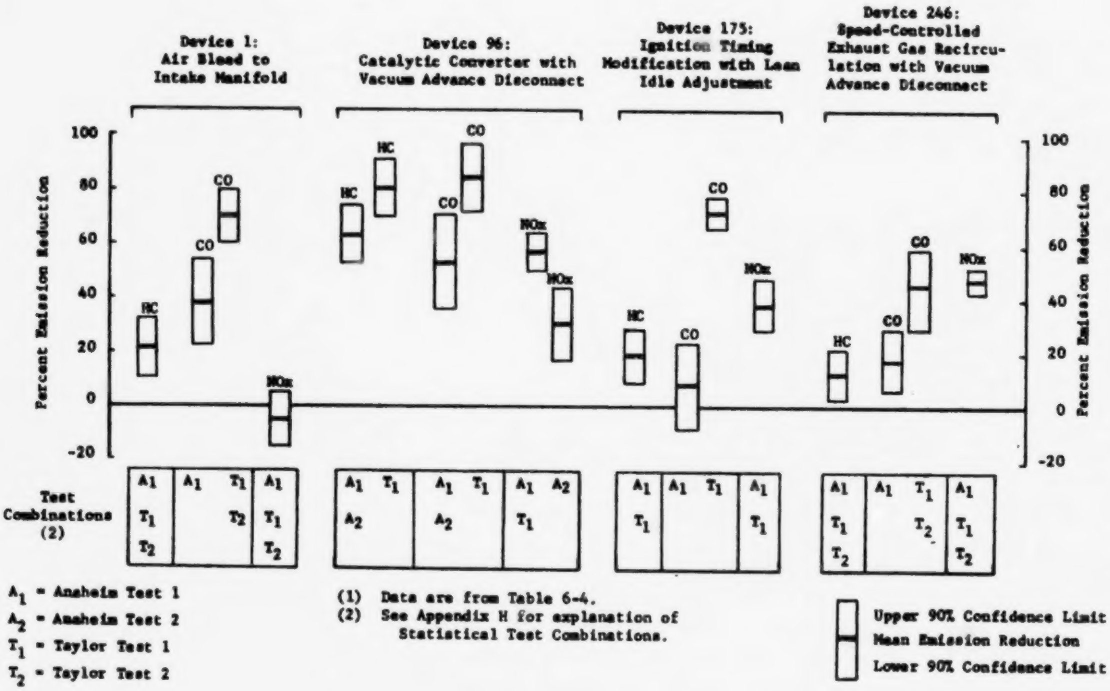


Figure 6-1. MEAN PERCENTAGE EMISSION REDUCTION AND 90 PERCENT CONFIDENCE LIMITS FOR EXHAUST EMISSION CONTROL RETROFIT SYSTEMS TESTED AT ANAHEIM, CALIFORNIA, AND TAYLOR, MICHIGAN

The general conclusions for this device are:

		90 Percent Confidence Intervals
HC	significant reduction, large	53 to 91 percent
CO	significant reduction, large	37 to 97 percent
NOx	significant reduction	17 to 64 percent

In summary the Anaheim and Taylor data for Device 96 could not be combined, but the reductions are large and statistically significant for all three pollutants.

These reductions are the average of all tests conducted with and without air pumps. Ten tests included air pumps and seven tests were conducted without air pumps. In each case the need for pump installation was determined by the developer at the time of device installation.

6.1.3 Device 175: Ignition Timing Modification with Lean Idle Adjustment

The Welch test allowed the Anaheim and Taylor test data to be combined for the HC and NOx percentage reduction (Figure 6-1). There was an extreme conflict of the CO data between Taylor and Anaheim and their reduction data were not combined.

The general conclusions for this device are:

		90 Percent Confidence Intervals
HC	significant reduction	9 to 29 percent
CO	conflict between two cities:	
	Anaheim	-8 to 23 percent
	Taylor	67 to 77 percent
NOx	significant reduction	27 to 47 percent

The CO test data were reviewed for anomalies to determine possible causes of the conflict in results between Anaheim and Taylor; none were found. Since Device 175 is an ignition timing modification with lean carburetor idle mixture by adjustment, it is not likely that this device controls the overall CO during a CVS test to a significant degree. It is known that lean idle mixture will reduce the overall CO level to some extent, but not to the extent shown in the Taylor data (an average of 72 percent, with confidence intervals of 67-77 percent CO reduction). For comparison, the Anaheim data showed a mean CO reduction of 8 percent with confidence intervals from -8 to 23 percent. This CO reduction may be more representative of this device.

In summary, Device 175 does control NOx and HC also, lean idle CO adjustment may reduce the overall CO levels to some degree in a 1972 Federal CVS test.

6.1.4 Device 246: Exhaust Gas Recirculation with Vacuum Advance Disconnect

The Anaheim and Taylor (Test 1 and 2) data were combined for HC and NOx. There was a conflict in the CO data between the Taylor and the Anaheim data (Figure 6-1). However, the Welch test allowed the Taylor Test 1 and the Taylor Test 2 CO data to be combined.

The general conclusions for this device are:

		90 Percent Confidence Limits
HC	significant reduction	3 to 21 percent
CO	significant reduction, ($T_1 + T_2$)	27 to 60 percent
CO	significant reduction, (A_1)	6 to 27 percent
NOx	significant reduction	43 to 52 percent

In summary, it appears that the exhaust gas recirculation system with vacuum advance disconnect is primarily an NOx control device and reduces HC and CO to a lesser extent.

6.1.5 Emission Reduction Versus Engine Size

The emission reduction data of the devices that received up to 18 tests were reviewed to determine if engine size had an effect on the magnitude of the emission reduction. Each emission reduction value was plotted with the corresponding engine cubic inch displacement (CID) for each device. In the retrofit program, seven engine sizes were selected for the test vehicles. These were engine sizes of 91, 194, 283, 289, 318, 327, and 390 CID (see Table 4-1, Section 4 for complete fleet description).

The plots showed that the emission reduction performance of the devices was independent of the engine size. The reduction performance varied considerably between cars, as well as between the same make and model car, but did not show any correlation to engine size for the group of seven engine sizes that were tested in the retrofit program.

6.1.6 Emission Index Results

The Emission Index (EI) is the average per unit reduction in HC, CO, and NOx emissions due to the installation of the retrofit device. The Emission Index is calculated from the equation defined in Section 3 and provides a method to rank order the emission reduction performance for each device.

Table 6-5 presents the Emission Index average values in rank order for all devices for which emission data were available. Table 6-5 is segregated by the test procedure used to calculate the Emission Index because the test data varies considerably with the test procedure, and the reliability of the test data also depends on the number of tests. The highest positive numerical index indicates that the device possesses the best overall emission reduction potential compared to the other devices. Negative emission index values indicate an overall emission increase above baseline emission levels. For the devices tested in the retrofit program, the EI represents the mean of the EI's for all tests of a device.

In the group of devices that received up to 18 tests in the retrofit program, the catalyst converter with vacuum advance disconnect (Device 96) ranked highest with a mean Emission Index of 0.60. The ignition timing modification with lean idle adjustment (Device 175) and exhaust gas recirculation with vacuum advance disconnect (Device 246) systems were almost equal and ranked second and third, respectively.

In the group that received up to three emission tests per device, the exhaust gas recirculation system (Device 10) ranked first.

In the developer and EPA data group, the LPG Conversion (Device 52) ranked high, with an Emission Index of 0.77 (18 tests).

6.2 DRIVEABILITY INDEX

The vehicle driveability tests conducted in the retrofit program followed the Automobile Manufacturers Association (AMA) driveability procedures (see paragraph 4.2.4.2). The driveability characteristics were measured both with and without the retrofit device installed.

Table 6-5. RANK ORDERED EMISSION INDEX VALUES BY TEST METHOD FOR RETROFIT DEVICES EVALUATED

NOTE: THE RELIABILITY OF THE DATA SHOWN DEPENDS ON THE TYPE OF TEST PROCEDURE AND NUMBER OF TESTS.

TEST TYPE	RANK	DEVICE	DESCRIPTION	DATA SOURCE(1)	NUMBER OF TESTS	EMISSION INDEX
1972 FEDERAL TEST PROCEDURE (CVS)			Retrofit Program Test Data (Up to 18 Tests for Each Device):			
	1	96	Catalytic Converter with Distributor Vacuum Advance Disconnect	R	17	0.596
	2	175	Ignition Timing Modification with Lean Idle Adjustment	R	10	0.343
	3	246	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	R	15	0.302
	4	1	Air Bleed to Intake Manifold	R	18	0.247
			Retrofit Program Test Data (Up to 3 Tests for Each Device):			
	1	10	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	R	2	0.396
	2	69	Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification	R	3	0.287
	3	42	Air Bleed to Intake Manifold	R	2	0.237
	4	33	Carburetor Modification, Main Jet Differential Pressure	R	2	0.118
	5	288	Carburetor Main Discharge Nozzle Modification	R	2	0.074
	6	295	Carburetor with Variable Venturi	R	1	0.028
	7	245	Variable Camshaft Timing	R	1	-0.139
			Developer and EPA Supplied Data:			
	1	52	LPG Conversion	E	18	0.771
	2	466	LPG-Gasoline Dual-Fuel Conversion	E	6	0.393
	3	418	Air Bleed to Intake Manifold	E	(2)	0.165
	4	292	Catalytic Converter	E	1	0.156
	5	100	Turbocharger	E	1	0.113
	6	465	Fuel Additive	E	1	0.101
	7	24	Heavy Duty Positive Crankcase Control Valve with Air Bleed	E	(4)	0.079
	8	172	Intake Manifold Modification	E	1	0.040
	9	462	Air Bleed to Intake and Exhaust Manifolds	E	(3)	0.024
	10	294	Exhaust Gas Recirculation with Carburetor Modification	E	1	-0.128
	11	23	Electronic Ignition Unit	E	1	-0.231
	12	95	Ignition Spark Modification	E	1	-0.251
	13	460	Compressed Natural Gas Dual-Fuel Conversion	E	1	-0.277
			No Baseline Given for the Following Devices: (5)			
	(6)	93	Catalytic Converter with Exhaust Gas Recirculation, Spark Modification, and Lean Idle Mixture	E	6	(6)
	(6)	459	LPG Conversion with Deceleration Unit	E	1	(6)
	(6)	461	LPG Conversion with Exhaust Reactor Pulse Air Injection and Exhaust Gas Recirculation	E	1	(6)
	(6)	463	Rich Thermal Reactor with Exhaust Gas Recirculation and Spark Retard	E	3	(6)
	(6)	464	Methanol Fuel Conversion with Catalytic Converter	E	6	(6)
	(6)	468	Lean Thermal Reactor with Exhaust Gas Recirculation	D	5	(6)
EPA9X7 CVS(11)	1	469	Rich Thermal Reactor with Exhaust Gas Recirculation and Particulate Control	E	2	0.630
7-CYCLE 7-MODE COLD START	1	425	Exhaust Gas Afterburner	D	1(9)	0.970(9)
	2	244	Rich Thermal Reactor	D	(6)	0.750(9)
	3	57	Air Bleed with Exhaust Gas Recirculation and Vacuum Advance Disconnect	D	1	0.516
	4	317	Carburetor Modification with Vacuum Advance Disconnect	D	3	0.297
	4	384	Air-Fuel Mixture Diffuser	D	1	0.297
	6	315	Closed Blowby Control System	D	1(9)	0.281(9)
	7	182	Fuel and Oil Additives	D	(7)	0.269
	8	430	Induction Modification	D	2	0.267
	9	62	Catalytic Converter	E	1	0.218
	10	59	Three-Stage Exhaust Gas Control System	D	1	0.204
	11	401	Air-Vapor Bleed to Intake Manifold	D	1	0.094
	12	164	Exhaust Gas Filter	D	1	0.040
	13	458	Air Bleed to Intake Manifold	E	(8)	-0.016
	14	36	Fuel Conditioning by Exposure to Electromagnetic Field	E	(9)	-0.065
	15	322	Exhaust Gas Backpressure Valve	E	1	-0.258

Table 6-5. RANK ORDERED EMISSION INDEX VALUES BY TEST METHOD FOR RETROFIT DEVICES EVALUATED (CONCL)

NOTE: THE RELIABILITY OF THE DATA SHOWN DEPENDS ON THE TYPE OF TEST PROCEDURE AND NUMBER OF TESTS.

TEST TYPE	RANK	DEVICE	DESCRIPTION	DATA SOURCE(1)	NUMBER OF TESTS	EMISSION INDEX
7-CYCLE 7-MODE COLD START (CONT)			No Baseline Given for the Following Devices:			
	(6)	22	Electronic Fuel Injection	E	1	(6)
	(6)	31	Thermal Reaction by Turbine Blower Air Injection	D	6	(6)
	(6)	56	Crankcase Blowby and Idle Air Bleed Modification	D	3	(6)
	(6)	160	Closed or Open Blowby Control System with Filter	D	1	(6)
7-CYCLE 7-MODE HOT START	1	325	Air-Vapor Bleed to Intake Manifold	D	7	0.239
	1	433	Air-Vapor Bleed to Intake Manifold	D	7	0.239
	3	427	Closed or Open Blowby Control System with Filter	D	2	0.182
	4	279	Fuel Conditioner	D	1	0.107
	5	170	Closed Blowby Control System	D	1	0.087
	6	296	Ignition Timing and Spark Modification	D	1	0.027
			No Baseline Given for the Following Device:			
	(6)	165	Exhaust Gas Afterburner/Recirculation with Blowby and Fuel Evaporation Recirculation	D	1	(6)
STEADY STATE	1	457	Water Injection	E	(11)	0.250(13)
	2	308	Exhaust Gas Afterburner	D	3(11)	-0.047
UNKNOWN			No Emission Data Provided by the Developer for the Following Devices:			
	(6)	259	Photocell-Controlled Ignition System	D	(6)	(6)
	(6)	268	Capacitive Discharge Ignition	D	(6)	(6)
	(6)	282	LP Gas Injection	D	(6)	(6)
	(6)	408	Exhaust Gas and Blowby Recirculation with Intake Vacuum Control and Turbulent Mixing	D	(6)	(6)
	(6)	440	Air-Fuel Mixture Deflection Plate	D	(6)	(6)
			No Emission Evaluation was Made on the Following Device:			
	(6)	467	Fuel Evaporation Control System	(6)	(6)	(6)

(1) R - Retrofit Test Program
D - Developer Supplied Data
E - Environmental Protection Agency (data references are presented in Volume II).
(2) 16 baseline and 11 device tests on 3 cars.
(3) 10 baseline and 9 device tests for HC and CO, and 6 baseline and 6 device tests for NOx, on 2 cars.
(4) 6 baseline and 5 device tests for HC and CO; 3 baseline and 4 device tests for NOx.
(5) See Volume II for emission levels with devices installed.
(6) Unknown.
(7) 4 tests for HC and CO; 1 test for NOx.
(8) 1 baseline and 2 device tests on 1 car.
(9) 1 baseline test and 11 device tests for HC and CO only.
(10) HC and CO only.
(11) Different steady state speeds.
(12) EPA Interim 9-Cycle, 7-Mode CVS Emission Test Procedure (refer to Volume II, Reference 16).
(13) For water-to-fuel ratio of 0.9:1.

The Driveability Index (DI) is the sum of the "without device" driving anomalies subtracted from the sum of the "with device" driving anomalies. Nine driveability parameters were observed, including rough idle, stumble, hesitation, detonation, stretchiness, surge, cranking time to start engine, stall at idle, and acceleration. Details of the Driveability Index equation are outlined in Section 3.

The weighting factors α_1 through α_{16} used in the general DI equation were derived from a set of basic weighting factors A_1 through A_{16} agreed upon as representative by project personnel. The basic weighting factors chosen represent the relative importance placed on each of the driveability test parameters. Hot start weighting factors were generally greater than the cold start weighting factors, because the relative time in the hot driving modes is greater than the cold driving modes.

Each of the parameters was subjected to a number of observations which required an entry on the driveability test form (a sample of this form is shown in Appendix G of Volume IV). Each entry was assigned a value of 0, 1, 2, or 3 for none, trace, moderate, or heavy occurrence of the respective driveability parameters. The number of possible entries on the DI test form is a constant for each of the parameters. This constant was incorporated into the DI weighting factors by dividing the basic weighting factor by the number of possible entries to form new weighting factors, α_i. Table 6-6 lists the values for the driveability weighting factors used in this study.

Table 6-6. WEIGHTING FACTORS USED FOR GENERAL DRIVEABILITY INDEX CALCULATIONS

	COLD							HOT								
	START		ACCELERATION					START	ACCELERATION							
DRIVEABILITY PARAMETER	ROUGH IDLE	STALL AT IDLE	STUMBLE	HESITATION	DETONATION	STRETCHINESS	SURGE	ROUGH IDLE	STUMBLE	HESITATION	DETONATION	STRETCHINESS	SURGE	COLD STARTING	HOT STARTING	0-60 MPH ACCEL
i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Basic weighting factor, A_i	1.0	5.0	0.5	0.5	0.5	0.5	0.5	4.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	5.0
Number of Possible entries on test form	3	3	60	60	1	60	60	2	20	20	20	20	20	1	1	1
Driveability parameter weighting factor, α_i	0.3333	1.6666	0.0083	0.0083	0.5	0.0083	0.0083	2.0	0.1	0.1	0.1	0.05	0.05	1.0	1.0	5.0

6.2.1 Driveability Index Results

Driveability Index values are listed in rank order in Table 6-7. Positive DI numbers represent a penalty and negative numbers indicate an improvement over baseline values.

The driveability results shown in Table 6-7 are for the devices tested in the retrofit program. Driveability data supplied by the developers were generally incomplete and therefore were not reported. For the devices tested in the retrofit program, the DI represents the means of the DI's for all tests of a device.

If there is no change in the driveability parameters with the retrofit device installed, as compared to the same vehicle without the device, the general driveability equation calculation would equal zero. For example, should an acceleration loss of three seconds be the only consequence of device installation, the DI would equal 1.25. This condition would cause the DI to exceed the "acceptable limit" level of 1.0 shown in the evaluation criteria (Table 3-1).

The devices which were tested in the retrofit program showed some degradation in driveability as a result of device installation. Device 295, which was a variable venturi carburetor, showed the worse DI rating at 3.3. Other DI values ranged from -0.459 to 0.895. Device 288 showed a DI of -0.459, which is the result of one test

Table 6-7. DRIVEABILITY INDEX RESULTS IN RANK ORDER FOR DEVICES TESTED IN RETROFIT PROGRAM

RANK	DEVICE	DESCRIPTION	NO. OF TESTS	DRIVE-ABILITY INDEX
Up to 18 Tests per Device				
1	246	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	13	0.113
2	175	Ignition Timing Modification with Lean Idle Adjustment	10	0.118
3	1	Air Bleed to Intake Manifold	18 (1)	0.138
4	96	Catalytic Converter with Distributor Vacuum Advance Disconnect	17	0.304
Up to 3 Tests per Device				
1	288	Carburetor Main Discharge Nozzle Modification	1	-0.459 (2)
2	69(3)	Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification	3	0.087
3	42	Air Bleed to Intake Manifold	2	0.116
4	33	Carburetor Modification, Main Jet Differential Pressure	2	0.181
5	10	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	2	0.441
6	245	Variable Camshaft Timing	1	0.895
7	295	Carburetor with Variable Venturi	1	3.261 (4)

(1) One more driveability test performed than emission test.

(2) Driveability Index based on one test; second test aborted.

(3) This device received an additional driveability test.

(4) It is possible that this DI is invalid due to an inadvertent maladjustment of the ignition timing.

on one vehicle. The negative sign was due to a 3.1-second average improvement in acceleration time as a result of device installation.

Mountain and desert driveability tests were conducted to evaluate Devices 1, 96, 175, and 246 under extreme environmental conditions. The purpose of the mountain tests was to determine the effects of cold weather and altitude (6,500 feet) on the test vehicle's operating characteristics with a retrofit device installed. The desert tests were conducted to determine the effects of warm weather on the operation of a retrofit system. The mountain driveability tests were conducted from the viewpoint of a vehicle owner's acceptance.

The mountain tests were conducted on one vehicle (Car 17) in the baseline configuration. Four device units that had already received laboratory tests were installed consecutively for the mountain and desert tests on the same car. The tests were conducted during the November 1971 test period. The temperatures in the mountains ranged from 35 to 42°F during the cold start driveability tests with soak temperatures of only 25°F. Unfortunately, the desert temperatures were cool, and ranged from 60 to 68°F during the hot start driveability tests.

During initial startup of the cold start driveaway test it was observed that the baseline vehicle had a very rich choke setting which was caused by the high altitude. (Carburetor air-fuel ratios are richer at high altitudes than air-fuel ratios near sea level where the Anaheim facility is located.)

In the mountain tests, the baseline vehicle had severe hesitation during the acceleration modes of the first few cycles of the cold start driveaway test. The hesitations were caused by the overrich mixture, which was confirmed by the emission of black smoke from the tailpipe. As the car warmed up, the hesitation and black smoke ceased, and the driveability was satisfactory for the remainder of the cold start driveability tests.

The same hesitation problem occurred for the cold start driveability tests conducted on the same vehicle with the retrofit devices installed. This was a car problem and was not attributable to the performance of the retrofit device. The choke was not readjusted for the first two tests (Devices 1 and 246). During the cold start of the third device test (Device 96), the choke was adjusted two notches leaner than the sea level setting. This was necessary because the vehicle would not continue to run during the initial portion of the cold start driveaway tests.

Once the choke began to open, the driveability was satisfactory for all four devices, 1, 96, 175 and 246, during the remainder of the cold start driveaway modes of operation.

Idle modes were satisfactory (smooth) for all devices; however, the idle speed of Device 246 (exhaust gas recirculation) dropped off to 400-450 rpm during the last portion of the cold start driveability procedure. The idle speed returned to normal during the hot start portion of the driveability tests for Device 246. All devices performed the hot start driveability test satisfactorily during the acceleration, cruise, and idle modes of operation.

In summary, the devices tested during the mountain and desert driveability tests caused no degradation to the vehicle's driveability characteristics.

6.2.2 Driveability Index Sensitivity Analysis

The purpose of this analysis was to determine the sensitivity of the DI to changes in the input parameters as a result of device installation or test measurement errors.

The sensitivity analysis approach was to determine the impact of one input parameter change on the DI while keeping all other input parameters constant. It was assumed that all DI parameters were independent of one another. Using this approach, the sensitivity of the DI to device performance characteristics or test measurement errors was determined by partial differentiation of each parameter.

A 20 percent change for each driveability term of the DI was used to calculate the absolute sensitivity of that term. This change was then compared to an overall nominal DI so that the sensitivity impact of that term could be evaluated. Sensitivity calculations for the DI terms are presented in Appendix J.

A summary of the DI sensitivity analysis calculations for a 20 percent input deviation is presented in Table 6-8.

The summary shows that a 20 percent deviation in the 0-60 acceleration times with a retrofit device installed could cause a Driveability Index change of 12 percent. The remaining DI terms are relatively insensitive to an input parameter deviation of 20 percent.

It must be recognized that the weighting factor for the acceleration parameter was 5 and the other parameters were weighted at 2 or less. The sensitivity of each term is dependent on the weighting factor of that term (see paragraph 3.2.2).

Table 6-8. SENSITIVITY ANALYSIS CALCULATION FOR THE DRIVEABILITY INDEX

PARAMETER DIFFERENTIAL INPUT DEVIATION = 20%	DRIVEABILITY INDEX DEVIATION (PERCENT)
Basic driveability characteristics (Cold and Hot Tests)	1.1
Cold and hot start cranking time	1.7
Acceleration time for 0 to 60 mph	12.5

6.3 COST INDEX

The Cost Index (CI) combines those parameters which determine the initial costs of a device and the recurring costs. The initial costs are measured in terms of device retail cost and installation cost amortized over the device lifetime in dollars per mile. The recurring costs are added expenses for keeping the retrofit device in operation after installation, and are expressed in dollars per mile driven. The initial costs and the recurring costs are combined to form the Cost Index formula:

$$CI = S_3 \left(\frac{\text{Device Installation Cost}}{\text{Useful Life}} + \text{Recurring Cost} \right) \text{Dollars/100 miles}$$

Details of the CI are outlined in paragraph 3.2.3. This section presents the results of the initial costs, recurring costs, and the Cost Index.

6.3.1 Initial Costs

The initial costs for the retrofit device installations are presented in Appendix K, which is grouped by device type. The initial costs of the more effective devices were generally higher than the less effective devices. For example, the initial cost of Device 96 (catalytic converter with distributor vacuum disconnect), which controls all three pollutants, was reported to be $175, including an air pump. At the other extreme, the less effective air-bleed-to-intake-manifold systems ranged from $23 (Device 42) to $64 (Device 1). The ignition timing modification system and the exhaust gas recirculation system initial costs ranged from $45 (Device 175) to $89 (Device 246), respectively.

The Criteria Index discussion of Section 5 denoted the devices that exceeded the $85 initial cost limit.

Device installation costs alone are not adequate in developing grounds for feasible versus infeasible systems. More appropriate discussion of device costs are included in the Cost Index and Cost Effectiveness Index discussions in paragraph 6.3.3 and Section 7, respectively.

6.3.2 Recurring Costs

The recurring costs of the retrofit devices are listed in Appendix K. For the devices tested in the retrofit program, the fuel consumption change due to the device is included in the recurring cost calculations. In most cases, the data supplied by the developer excluded fuel consumption change due to the devices and, therefore, were not included in the recurring cost calculations listed in Appendix K. The fuel consumption changes as a result of a retrofit device installation are presented in Appendix L for the devices tested in the retrofit program.

Table 6-9 lists the average percentage change in fuel consumption for the devices that received up to 16 tests. The test data listed in Appendix L show similar car-to-car variability to the percentage emission reduction variability presented in the emission reduction statistical results (Table 6-4). However, the average fuel consumption listed in Table 6-9 does give some indication of the fuel consumption change caused by each retrofit device.

The air bleed system (Device 1) produced a 4 percent average increase in fuel mileage (more miles per gallon). Since the air bleed system is a "leaning" device, some vehicles with relatively rich carburetor mixtures may experience better gas mileage. However, if this system were installed on a vehicle that is already lean, mileage might be degraded because of an excessively lean mixture.

The catalytic system caused a 1 percent average decrease in fuel mileage (Table 6-9). This change may reflect a slight increase in exhaust gas backpressure due to the device and to disconnecting the vacuum advance line to the distributor.

Table 6-9. AVERAGE FUEL MILEAGE CHANGE FOR EXHAUST EMISSION CONTROL RETROFIT SYSTEMS TESTED AT ANAHEIM, CALIFORNIA, AND TAYLOR, MICHIGAN (1)

DEVICE NO.	NO. OF TESTS (2)	AVERAGE MILEAGE CHANCE (3)
1	14	4% Increase
96	16	1% Decrease
175	9	10% Decrease
246	11	7% Increase

(1) Average change was calculated from data in Appendix L. Fuel consumption was measured during the 1972 Federal Test Procedure for emissions.

(2) Includes replicate tests.

(3) "Increase" means more miles per gallon.

The ignition timing modification system (Device 175) showed an average decrease in fuel mileage of 10 percent. This system retards the distributor advance during low speed operation, which may cause the negative effect on fuel consumption.

The exhaust gas recirculation (EGR) system (Device 246) produced a 7 percent increase in fuel mileage (better gas mileage) which may be attributable to better fuel vaporization. This may be caused by the mixing of the recirculated exhaust gas with the carburetor air-fuel mixture. This factor may overshadow the negative performance effect of distributor vacuum disconnect, which also is part of Device 246.

6.3.3 Cost Index Results

Table 6-10 tabulates the CI values in rank order. Devices are rated relatively worse as their CI values increase, because the increased cost is a penalty. Negative values for the CI represent a cost savings attributable to improved fuel economy.

When recurring costs were computed, the effect of increased fuel consumption was excluded for those devices which were not tested in the retrofit program. This was necessary because most developers did not submit fuel consumption data, and many of those who did, reported questionable improvements in economy. For the devices tested in the retrofit program, the CI represents the means of the CI's for all tests of a device.

The mean-miles-before-total-failure (MMBTF) was used as the device lifetime. The MMBTF in most cases exceeded the expected remaining lifetimes of the uncontrolled vehicles on which retrofit devices would be installed. Using the recurring cost criterion of $0.125 per 100 miles and a maximum allowed installed device cost of $85.00, amortized over an assumed average device lifetime of 50,000 miles, a nominal CI of $0.360 per 100 miles was obtained in the CI sensitivity analysis (paragraph 6.3.4).

In the group of devices which received up to 18 tests, the CI's for the exhaust gas recirculation system (Device 246) and the air bleed system (Device 1) were less than the nominal CI of $0.360 per 100 miles.

Table 6-10. COST INDEX IN ORDER OF RANK FOR RETROFIT DEVICES WITH COST DATA (REFERENCE APPENDIX K)

RANK	DEVICE NO.	DESCRIPTION	NO. OF TESTS	COST INDEX ($/100 MILES)
a. Devices with up to 18 Tests in Retrofit Program:				
1	1	Air Bleed to Intake Manifold	18	0.063(1)
2	246	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	15	0.079
3	175	Ignition Timing Modification with Lean Idle Adjustment	10	0.391
4	96	Catalytic Converter with Distributor Vacuum Advance Disconnect	17	0.521(2)
b. Devices with up to 3 Tests in Retrofit Program:				
1	33	Carburetor Modification, Main Jet Differential Pressure	2	-0.229
2	42	Air Bleed to Intake Manifold	2	-0.161
3	69	Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification	3	0.152
4	288	Carburetor Main Discharge Nozzle Modification	2	0.198
5	10	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	2	0.204
6	245	Variable Camshaft Timing	1	0.364
7	295	Carburetor with Variable Venturi	1	0.536
c. Devices with Cost Based on Developer and EPA Data (3):				
1	440	Air-Fuel Mixture Deflection Plate	See Note (3)	0.020
2	430	Induction Modification	See Note (3)	0.030
3	296	Ignition Timing and Spark Modification	See Note (3)	0.031
4	279	Fuel Conditioner	See Note (3)	0.033
5	268	Capacitive Discharge Ignition	See Note (3)	0.046
6	24	Heavy Duty Positive Crankcase Control Valve with Air Bleed	See Note (3)	0.047
7	317	Carburetor Modification with Vacuum Advance Disconnect		0.052
8	170	Closed Blowby Control System	See Note (3)	0.065
9	259	Photocell-Controlled Ignition System	See Note (3)	0.104
10	172	Intake Manifold Modification	See Note (3)	0.105

Table 6-10. COST INDEX IN ORDER OF RANK FOR RETROFIT DEVICES WITH COST DATA (CONCL)

RANK	DEVICE NO.	DESCRIPTION	NO. OF TESTS	COST INDEX ($/100 MILES)
11	56	Crankcase Blowby and Idle Air Bleed Modification	See Note (3)	0.1[illegible]0
12	408	Exhaust Gas and Blowby Recirculation with Intake Vacuum Control and Turbulent Mixing	See Note (3)	0.139
13	160	Closed or Open Blowby Control System with Filter	See Note (3)	0.143
14	315	Closed Blowby Control System	See Note (3)	0.175
15	57	Air Bleed with Exhaust Gas Recirculation and Vacuum Advance Disconnect	See Note (3)	0.188
16	292	Catalytic Converter	See Note (3)	0.192
17	164	Exhaust Gas Filter	See Note (3)	0.205
18	52	LPG Conversion	See Note (3)	0.224
18	459	LPG Conversion with Deceleration Unit	See Note (3)	0.224
20	308	Exhaust Gas Afterburner	See Note (3)	0.250
21	427	Closed or Open Blowby Control System with Filter	See Note (3)	0.271
22	282	LP Gas Injection	See Note (3)	0.309
23	31	Thermal Reaction by Turbine Blower Air Injection	See Note (3)	0.337
24	425	Exhaust Gas Afterburner	See Note (3)	0.377
25	401	Air-Vapor Bleed to Intake Manifold	See Note (3)	0.442
26	325	Air-Vapor Bleed to Intake Manifold	See Note (3)	0.454
26	433	Air-Vapor Bleed to Intake Manifold	See Note (3)	0.454
28	244	Rich Thermal Reactor	See Note (3)	0.536
29	165	Exhaust Gas Afterburner/Recirculation with Blowby and Fuel Evaporation Recirculation	See Note (3)	0.549
	(1)	Based on initial cost of $64.		
	(2)	Based on initial cost of $175.		
	(3)	Fuel consumption data (if any) measured during developer emission test programs were generally not reported; therefore, fuel consumption was not included in the Cost Index calculation for these devices and the number of tests is not pertinent in these cases.		

6.3.4 Cost Index Sensitivity Analysis

A sensitivity analysis was performed on the CI. The purpose of this analysis was to determine the sensitivity of the Cost Index to change in the input parameters as a result of device installation or test measurement errors.

A sensitivity analysis determines the impact of a change in one measurement upon the CI while keeping all other input parameters constant. It was assumed that each parameter of the CI was independent of one another. On this basis, the sensitivity of the CI to test measurement errors or to the retrofit device performance characteristics was determined by partial differentiation of each parameter. Calculations of the CI sensitivity analysis are presented in Appendix J.

A change of 20 percent was used to calculate the sensitivity of each CI parameter. This change was then compared to the overall CI so that the sensitivity of the CI could be evaluated. A summary of the cost sensitivity analysis calculations for a 20 percent input deviation is presented in Table 6-11.

The CI sensitivity analysis results show that a 10 percent loss in the fuel mileage increases the CI by 62 percent. The remaining CI terms are relatively insensitive to a 20 percent input deviation, with output deviations ranging from 4 to 10 percent.

Table 6-11. COST INDEX SENSITIVITY ANALYSIS RESULTS

NOMINAL COST INDEX = \$3.60/1,000 MILES	
PARAMETER INPUT DEVIATION = 20%	COST INDEX OUTPUT DEVIATION (PERCENT)
Mean miles before total failure	9.5
Mean miles before partial failure	7.2
Mean miles before maintenance	3.8
Fuel mileage loss due to device (1)	62.0
Labor cost	5.7
(1) 10% loss in fuel mileage	

6.4 PERFORMANCE INDEX

The Performance Index (PI) is made up of the Emission Index (EI), Driveability Index (DI), and the Cost Index (CI), with units of per unit reduction, nondimensional, and dollars per 100 mile, respectively.

From Section 3, the Performance Index equation (Eq. 3.2) is:

$$PI = \frac{C_1(EI) - C_2(DI) - C_3(CI)}{C_1 + C_2 + C_3} \qquad (6.1)$$

Where:

C1, C2, and C3 are weighting factors.

The Emission Index represents an emission reduction benefit while the Driveability and Cost Indexes represent penalties; hence the minus signs.

6.4.1 Performance Index Results

There were sufficient data available to compute the Performance Index (PI) of the devices tested in the retrofit program. The devices that received only an engineering analysis lacked driveability data from the developer and, therefore, the PI could not be calculated. For those devices tested in the retrofit program, the PI was calculated as the mean of the PI's for all tests of a device.

Table 6-12 presents the mean PI results in rank order. The Emission, Driveability, and Cost Index values are also presented for evaluation of the PI rankings.

The weighting coefficients used to perform the PI calculations weigh emission reduction benefits twice as heavy as cost penalties, which are, in turn, weighted twice as heavy as driveability penalties. It should be noted that these weighting coefficients were used as an example and may not necessarily apply to all situations. A different set of coefficients may be used in the PI equation to obtain different PI values (see paragraph 6.4.2).

Among the devices with up to 18 tests, the catalyst system (Device 96) ranked first, with a PI of 0.163 due to its high Emission Index. The Cost Index for Device 96 is the highest among the other systems. This system in its present state of development includes an air pump. The total price ($175.00 installed) could be reduced substantially if the air pump could be eliminated.

The exhaust gas recirculation system with the vacuum advance disconnect (Device 246) showed a PI of 0.134. The major reason for this value is that the CI and DI are substantially lower than for other devices in this group.

The air-bleed system (Device 1) ranked third with a PI of 0.103 in the group which received up to 18 tests. The primary reason for this ranking is the relatively low Emission Index of 0.247.

The ignition timing system (Device 175) was fourth in this group, because of its relatively high Cost Index.

Device 33 ranked highest in the group of devices which received up to three tests. However, the Cost Index is $-0.229 per 100 miles, which reflects a fuel consumption saving during the CVS tests. This Cost Index mean is based on only two tests and may show a different value for a larger test sample.

Two of the devices in the group of devices which received two tests had negative PI values. In these cases, the penalties of the Driveability and Cost Indexes are greater than the benefits of the Emission Index.

6.4.2 Weighting Coefficient Sensitivity Analysis

The purpose of this analysis was to determine the impact that changing the weighting coefficients of the Emission, Driveability, and Cost Indexes would have on the Performance Index. This analysis provides the evaluator with a choice of weighting coefficients that would allow him to weight a particular index less than (or more than) the weightings used in the preceding PI calculations.

Table 6-12. MEAN PERFORMANCE INDEX RESULTS IN RANK ORDER FOR DEVICES TESTED IN RETROFIT PROGRAM

PERFORMANCE INDEX RANK.	DEVICE	DESCRIPTION	NO. OF TESTS	PERFORMANCE INDEX(1)	EMISSION INDEX(2)	DRIVEABILITY INDEX(3)	COST INDEX $/100mi(4)
Devices with up to 18 Tests (1972 Federal Test Procedure):							
1	96	Catalytic Converter with Distributor Vac Advance Disconnect	17	0.163	0.596	0.304	0.521(6)
2	246	Speed-Controlled Exh. Gas Recirculation with Vacuum Advance Disconnect	15	0.134	0.302	0.113	0.079
3	1	Air Bleed to Intake Manifold	18	0.103	0.247	0.138	0.063(5)
4	175	Ign. Timing Modification with Lean Idle Adjustment	10	0.067	0.343	0.118	0.391
Devices with up to 3 Tests (1972 Federal Test Procedure):							
1	33	Carburetor Modification, Main Jet Differential Pressure	2	0.174	0.118	0.181	-0.229(7)
2	42	Air Bleed to Intake Manifold	2	0.165	0.237	0.116	-0.161(7)
3	69	Electronic-Controlled Vacuum Advance Disconnect and Carb Lean Idle Modification	3	0.110	0.287	0.087	0.152
4	10	Throttle-Controlled Exh. Gas Recirculation with Vac. Adv. Disc.	2	0.105	0.396	0.441	0.204
5	288	Carburetor Main Discharge Nozzle Modification	2	0.054	0.074	-0.459(8)	0.198
6	245	Variable Camshaft Timing	1	-0.312	-0.139	0.895	0.364
7	295	Carburetor with Variable Venturi	1	-0.603	0.028	3.261	0.536

(1) Based on weighting factors of $C_1 = 4$, $C_2 = 1$, and $C_3 = 2$.
(2) Data from Table 6-5.
(3) Data from Table 6-7.
(4) Data from Table 6-10.
(5) Based on initial cost of $64.
(6) Based on initial cost of $175.
(7) Negative sign indicates a cost savings.
(8) Average acceleration times improved 3.1 seconds as a result of device installation. This was based on one test only (Appendix D).

The sensitivity of the Performance Index equation was determined by using the following sets of weighting coefficients:

WEIGHTING COEFFICIENT APPLICATION	WEIGHTING COEFFICIENT SET			
	1(1)	2(2)	3(2)	4(2)
For the Emission Index: C_1	4	9	16	10
For the Driveability Index: C_2	1	1	1	1
For the Cost Index: C_3	2	3	4	1

(1) This set used in retrofit program (paragraph 6.4.1)
(2) Alternate sets of weighting coefficients

The rationale for the selection of these coefficients is presented in paragraph 3.4 of Section 3. The Performance Index (PI) results obtained from the use of these alternate coefficients are presented in Table 6-13 for the devices tested in the retrofit program. Negative PI values appear when the Driveability or Cost Index penalties exceed the Emission Index value.

In the group of devices which received up to 18 tests, the catalytic reactor (Device 96) was at the top of the rankings for all weightings due to its high Emission Index for three of the four sets of coefficients.

The exhaust gas recirculation system ranked second for all four sets of coefficients due to its low Cost Index.

Table 6-13. PERFORMANCE INDEX WITH ALTERNATE WEIGHTING COEFFICIENTS FOR DEVICES TESTED IN RETROFIT PROGRAM

RANK	DEVICE	DESCRIPTION	PI	RANK	DEVICE	DESCRIPTION	PI	RANK	DEVICE	DESCRIPTION	PI	RANK	DEVICE	DESCRIPTION	PI
Devices with up to 18 tests (1972 Federal Test Procedure)															
1	96	Catalyst	0.163	1	96	Catalyst	0.277	1	96	Catalyst	0.345	1	96	Catalyst	0.436
2	246	EGR	0.134	2	246	EGR	0.208	2	246	EGR	0.236	2	246	EGR	0.261
3	1	Air Bleed	0.103	3	175	Ign. Mod.	0.139	3	175	Ign. Mod.	0.182	3	175	Ign. Mod.	0.244
4	175	Ign. Mod.	0.067	4	1	Air Bleed	0.135	4	1	Air Bleed	0.160	4	1	Air Bleed	0.185
Devices with up to 3 tests (1972 Federal Test Procedure)															
1	33	Carb. Mod.	0.174	1	42	Air Bleed	0.192	1	10	EGR	0.237	1	10	EGR	0.274
2	42	Air Bleed	0.165	2	10	EGR	0.188	2	42	Air Bleed	0.206	2	69	Ign. & Idle Mod.	0.217
3	69	Ign. & Idle Mod.	0.110	3	69	Ign. & Idle Mod.	0.150	3	69	Ign. & Idle Mod.	0.180	3	42	Air Bleed	0.201
4	10	EGR	0.105	4	33	Carb. Mod.	0.115	4	33	Carb. Mod.	0.120	4	33	Carb. Mod.	0.100
5	288	Carb. Mod.	0.054	5	288	Carb. Mod.	0.042	5	288	Carb. Mod.	0.041	5	288	Carb. Mod.	0.084
6	245	Var. Cam Tim.	-0.312	6	245	Var. Cam. Tim.	-0.249	6	245	Var. Cam. Tim.	-0.218	6	245	Var. Cam. Tim.	-0.221
7	295	Carb. Repl.	-0.603	7	295	Carb. Repl.	-0.354	7	295	Carb. Repl.	-0.235	7	295	Carb. Repl.	-0.293
Weighting Coefficients															
Set 1 (1)				Set 2 (2)				Set 3 (2)				Set 4 (2)			
$C_1 = 4$	$C_2 = 1$	$C_3 = 2$		$C_1 = 9$	$C_2 = 1$	$C_3 = 3$		$C_1 = 16$	$C_2 = 1$	$C_3 = 4$		$C_1 = 10$	$C_2 = 1$	$C_3 = 1$	

C_1 = Emission Index Coefficient

C_2 = Driveability Index Coefficient

C_3 = Cost Index Coefficient

(1) This group of coefficients used to calculate PI of devices in retrofit program.

(2) These groups of coefficients used to calculate alternate PI of devices in retrofit program.

SECTION 7

COST EFFECTIVENESS INDEX

The Cost Effectiveness Index (CEI) provides additional information to complement the Performance Index of a retrofit device. Should two or more devices have about the same Performance Index, the one with the highest Cost Effectiveness Index would be preferred.

"Cost effectiveness" is usually defined as the rate of the desired results or the desired output versus the required cost input. In this discussion, the CEI is defined as the ratio of a device's Emission Index to its Cost Index. In evaluating an emission control device, the Emission Index (the desired output) is the weighted per unit reduction for all three pollutants. The Cost Index (the required cost input) is expressed as the total cost to the vehicle owner, in dollars per 100 miles driven, to buy, install, operate, and maintain the device.

The Cost Effectiveness Index is expressed by the equation:

$$\text{CEI} = \frac{\text{Emission Index, per Unit Reduction}}{\text{Cost Index, \$ per 100 miles}}$$

Table 7-1 lists the CEI results with the devices ranked according to highest cost effectiveness by test procedure and number of tests. The Performance Index (PI), Emission Index (EI), and the Cost Index (CI) are included in Table 7-1, for comparison with the CEI.

As stated above, the CEI complements the PI. For a thorough, comparative analysis of device performance, the evaluator should also incorporate and review the Emission and Cost Indexes. The reason for this is that the CEI ratio by itself may not reveal the difference between two devices that have different Emission and Cost Indexes, but the same CEI.

The evaluator must question the merits of a device to fit his requirements. He must ask "How much emission reduction do I need to fit my requirements, and how much money will it cost for that reduction?" Once he has these questions answered, he may then compare devices by reviewing their Performance Indexes.

In the group of devices that received up to 18 tests in the retrofit program, the CEI for the air bleed system (Device 1) ranked first and the exhaust recirculation system with vacuum advance disconnect (Device 246) ranked second (Table 7-1. The catalyst device (96) had the highest Emission and Cost Indexes among devices in this group.

The CEI for the ignition timing modification system with lean idle adjustment (Device 175) ranked fourth in the group that received up to 18 tests.

In the retrofit group which received up to three tests, Device 42 showed the best CEI (Table 7-1). For Devices 33 and 42, the negative CEI signs resulted from a fuel savings in the recurring cost portion of the Cost Indexes. Device 245 showed a negative CEI because of its negative Emission Index (a negative EI denotes an increase in emission levels above baseline).

Table 7-1. COST EFFECTIVENESS INDEX IN ORDER OF RANK FOR RETROFIT DEVICES WITH COST AND EMISSION DATA

NOTE: THE RELIABILITY OF THE DATA SHOWN DEPENDS ON THE TYPE OF TEST PROCEDURE AND NUMBER OF TESTS.

CEI RANK	DEVICE NO.	DESCRIPTION	NO. OF TESTS	COST EFFECTIVENESS INDEX	PERFORMANCE INDEX	EMISSION INDEX (PER UNIT REDUCTION)	COST INDEX ($/100 MILES)	TYPE OF TEST
a. Devices with up to 18 Tests in the Retrofit Program:								
1	1	Air Bleed to Intake Manifold	18	3.92	0.103	0.247	0.063(12)	(9)
2	246	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	15	3.82	0.134	0.302	0.079	(9)
3	96	Catalytic Converter with Distributor Vacuum Advance Disconnect	17	1.14	0.163	0.596	0.521(13)	(9)
4	175	Ignition Timing Modification with Lean Idle Adjustment	10	0.88	0.067	0.343	0.391(13)	(9)
b. Devices with up to 3 Tests in the Retrofit Program:								
1	42	Air Bleed to Intake Manifold	2	-1.47(1)	0.165	0.237	-0.161	(9)
2	33	Carburetor Modification, Main Jet Differential Pressure	2	-0.51(1)	0.174	0.118	-0.229	(9)
3	10	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	2	1.94	0.105	0.396	0.204	(9)
4	69	Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification	3	1.89	0.110	0.287	0.152	(9)
5	288	Carburetor Main Discharge Nozzle Modification	2	0.37	0.054	0.074	0.198	(9)
6	295	Carburetor with Variable Venturi	1	0.05	-0.603(3)	0.028	0.536	(9)
7	245	Variable Camshaft Timing	1	-0.38(4)	-0.312	-0.139(2)	0.364	(9)
c. Devices Evaluated Based on Developer and EPA Data: (6)								
1	430	Induction Modification	2	8.90	(5)	0.267	0.030	(10)
2	317	Carburetor Modification with Vacuum Advance Disconnect	3	5.71	(5)	0.297	0.052	(10)
3	52	LPG Conversion	18	3.44	(5)	0.771	0.224	(9)
4	279	Fuel Conditioner	1	3.24	(5)	0.107	0.033	(11)
5	57	Air Bleed with Exhaust Gas Recirculation and Vacuum Advance Disconnect	1	2.74	(5)	0.516	0.188	(10)
6	425	Exhaust Gas Afterburner	1(8)	2.57	(5)	0.970(8)	0.377	(10)
7	24	Heavy Duty Positive Crankcase Control Valve with Air Bleed	(14)	1.68	(5)	0.079	0.047	(9)
8	244	Rich Thermal Reactor	(7)	1.39	(5)	0.750(8)	0.536	(10)
9	170	Closed Blowby Control System	1	1.34	(5)	0.087	0.065	(11)
10	296	Ignition Timing and Spark Modification	1	0.87	(5)	0.027	0.031	(11)
11	292	Catalytic Converter	1	0.81	(5)	0.156	0.192	(9)
12	427	Closed or Open Blowby Control System with Filter	2	0.67	(5)	0.182	0.271	(11)
13	325	Air-Vapor Bleed to Intake Manifold	7	0.53	(5)	0.239	0.454	(11)
13	433	Air-Vapor Bleed to Intake Manifold	7	0.53	(5)	0.239	0.454	(11)
14	172	Intake Manifold Modification	1	0.38	(5)	0.040	0.105	(9)
15	401	Air-Vapor Bleed to Intake Manifold	1	0.21	(5)	0.094	0.442	(10)
16	164	Exhaust Gas Filter	1	0.19	(5)	0.040	0.205	(10)
17	308	Exhaust Gas Afterburner	3	-0.19(4)	(5)	-0.047(2)	0.250	(15)

(1) A cost savings was achieved as well as an emission reduction.

(2) Emissions were increased by the device.

(3) Large Driveability Index caused PI to be negative.

(4) Negative CEI caused by negative Emission Index (emission increase).

(5) Performance Index not calculated due to inadequate driveability data from developer.

(6) Fuel consumption data not available and therefore excluded from recurring costs and Cost Index.

(7) Unknown.

(8) Based on HC and CO data only.

(9) 1972 Federal Test Procedure.

(10) 7-cycle, 7-mode cold start.

(11) 7-cycle, 7-mode hot start.

(12) Based on initial cost of $64.

(13) Based on initial cost of $175 and unleaded gasoline at $0.38/gallon. For the other devices leaded gasoline was used at $0.35/gallon.

(14) 6 baseline and 5 device tests for HC and CO; 3 baseline and 4 device tests for NOx.

(15) Different steady state speeds.

SECTION 8

GUIDELINES FOR SELECTING AND IMPLEMENTING RETROFIT METHODS

A retrofit device is technically feasible if its overall effectiveness in reducing emissions, considering any undersirable effects on driving quality and operating safety, is sufficient to justify the costs of obtaining that effectiveness. The feasible use of retrofit devices, however, depends on their effectiveness and costs for particular emission control applications. In this context, a device, because of the fewer number of pollutants it controls or the lesser magnitude of control it achieves, might appear infeasible when compared with other devices. For another set of conditions, however, the same device could be entirely adequate for a particular emission control situation in which the scope and magnitude of control offered by the device is exactly what is needed. Ultimately, therefore, retrofit device feasibility depends on the emission control situations faced by individual air quality control regions. Specific criteria for judging feasibility should be established in accordance with the emission control requirements of these regions.

The analytical techniques developed in this study to evaluate the many different types of retrofit devices, together with the comprehensive laboratory testing program performed, have provided valuable insight into selection methodology and certification or accreditation criteria that could be used by any air pollution control agency in planning and implementing a retrofit method control strategy for reducing vehicle emissions. The overall approach which can be used to select and implement a retrofit method of control should include these basic steps:

a. Defining the emission reduction that would be required from the used car population.

b. Defining the characteristics of the used vehicle population to which retrofit methods would be applicable.

c. Identifying feasible retrofit methods for application to that vehicle population.

d. Determining which retrofit methods are most cost effective for the desired level of emission control.

e. Defining the retrofit device certification program.

f. Conducting the cost effectiveness studies required to verify the retrofit program approach.

g. Preparing an implementation plan.

h. Initiating and maintaining management control of the plan.

Guidelines for implementing these steps are discussed below.

8.1 DEFINING THE REQUIRED EMISSION REDUCTION

In accordance with the Clean Air Amendments Act of 1970, each State is required to submit a plan which provides for implementation, maintenance, and enforcement of each national primary and secondary ambient air quality standard promulgated by the Environmental Protection Agency for any air pollutant. As part of this plan, each State is required to specify the emission limitations that will be implemented to ensure attainment of the national primary and secondary standards for air quality. In some States, it may be necessary to specify and enforce emission limits on motor vehicles that did not incorporate emission controls as part of their production configuration. The specification of such emission limitations would be necessary when the air pollution levels within the State as a whole, or in certain air basins or air quality control regions, exceed the specified air quality standards.

Excessive levels of air pollution for pollutants having a national standard would exist whenever the specified standard is exceeded. To determine whether the standards are being met, each State is required to include in its implementation plan, provisions for establishing and operating methods or systems and procedures for monitoring, compiling, and analyzing data on ambient air quality.

These data are the means for determining whether emission controls are required on used cars so as to keep HC, CO, and NOx within the limits which will enable the national primary and secondary ambient air quality standards for these pollutants to be met. Once a State or air quality control region knows the levels of pollution existing in the ambient air, then a determination can be made as to the degree of control required on the emission sources of pollution. The amount of pollution caused by uncontrolled vehicles, or from controlled vehicles, has to be sufficiently detrimental to human health and welfare to justify the introduction of new or additional controls. This level of pollution exists when the ambient air quality standards are exceeded; for these standards are set on the basis of the pollutant levels that must not be exceeded if human health and welfare is to be protected from any known or anticipated adverse effects associated with the presence of air pollutants in the ambient air.

In some regions, ambient air quality may be entirely acceptable in terms of the national standards. In such areas, emission controls on used cars may not be a requirement. To determine whether vehicle emission control is needed, a State or air quality control region must have an air quality instrumentation network by which to monitor the pollutant levels of the ambient air. This would be prerequisite to any system for managing air quality, and is a basic requirement of the Clean Air Amendments Act of 1970.

8.2 DEFINING THE UNCONTROLLED VEHICLE POPULATION

With the need for vehicle emission control established, it is then necessary to determine the specific number and types of vehicles which must be controlled. This determination is required both to establish what type of retrofit method or methods would be most suitable and what type of management plan should be used to control the implementation, maintenance, and enforcement of these retrofit methods. Knowing this population also verifies that vehicle emissions are the source of the air pollution problem.

Defining the vehicle population is an essential first step toward defining a plan of control. The vehicle population has to be defined in terms of its geographic distribution, density by geographic area, model year, engine displacement, and type of ownership. A detailed survey is required to establish a definitive profile of the vehicle population. Geographic distribution and density must be determined, to establish vehicle population centers. These centers constitute emission source concentrations that can be studied for the optimum means of control. In some cases, the vehicle density and meteorological characteristics of an air basin may be so incompatible that even the most effective retrofit method of emission control would not be able to keep the vehicle emissions down to the level at which ambient air quality standards could be met. Vehicle density studies may show that land use or transportation controls may have to be used in combination with retrofit controls, to achieve a satisfactory level of control.

The determination of vehicle population centers also is an essential input to the management plan for implementing and controlling the retrofit program. As part of the vehicle survey, owner attitudes can be polled to obtain insight as to the acceptability of controls and the means by which controls should be instituted both administratively and financially. The type of ownership will also influence these management decisions. Vehicle ownership profiles would be established in terms of number of vehicles owned, model years, type of usage, and owner age and income bracket. Some vehicles may be fleet operated. It may be found that a population center is a low income area. Such factors influence how a retrofit program should be financed, whether by general indirect tax, license fees, or direct purchase.

The types of vehicles within the population centers are key factors in selecting the types of emission control to be used. As shown by Table 8-1, many model years are already controlled. In California, piston blowby controls were incorporated on the crankcases of new vehicles on a mandatory basis in 1961. These controls were incorporated nationally in 1963. Exhaust emission controls were required by California in 1966 and nationally in 1968. Fuel evaporation controls followed, in California in 1970 and nationally in 1971. These controls all affect HC and CO. NOx will be controlled in 1973, nationwide, and has been controlled since 1971 in California.

As indicated in Table 8-1, a range of retrofit controls may be applicable to a vehicle population center. To determine specifically what types of retrofit methods are required, a population center has to be broken down by vehicle model year, cubic inch engine displacement, type of emission control already incorporated, if any, and type of pollution control required. From this breakdown, a determination can be made as to the types of retrofit methods available to control these vehicles.

8.3 IDENTIFYING CANDIDATE RETROFIT METHODS

In accordance with the Clean Air Amendments Act of 1970, the Environmental Protection Agency is required to publish information on control techniques for meeting ambient air quality standards. Based on the results of the retrofit study and other studies, EPA will publish and maintain information on techniques or methods for controlling emissions from used cars. States and air pollution control agencies will be able to refer to this information to identify methods which appear to be applicable to their respective air pollution control requirements.

Table 8-1. LIGHT-DUTY VEHICLE POPULATION AND TYPE OF EMISSION CONTROL (1)
(REFERENCE 14)

ITEM	MODEL YEAR	AGE		PERCENT OF TOTAL	VEHICLE QUANTITY (MILLIONS)	DEGREE OF CONTROL			
		YEARS	MILEAGE (1)			EXHAUST	BLOW-BY	EVAPORATION	PERCENT TOTAL
1	1970	1.5	13,100	9	8.5	▧ ▒	▧ ▒	▨	32
2	1969	2.5	22,500	12	11.0	▧ ▒	▧ ▒		
3	1968	3.5	31,900	11	10.2	▧ ▒	▧ ▒		
4	1967	4.5	41,300	10	9.3	▨	▧ ▒		42
5	1966	5.5	50,700	9	8.5	▨	▧ ▒		
6	1965	6.5	60,100	9	8.5		▧ ▒		
7	1964	7.5	69,500	7	6.8		▧ ▒		
8	1963	8.5	78,900	7	6.8		▧ ▒		
9	1962	9.5	88,300	6	6.0		▨		26
10	1961	10.5	97,700	5	4.9		▨		
11	1960	11.5	107,100	4	4.3				
12	1959	12.5	116,500	3	3.4				
13	1958	13.5	125,900	3	3.4				
14	1957	14.5	135,300	1	1.7				
15	1956	15.5	144,700	1	1.7				
16	1955–	16.5+	154,100+	3	3.4				

(1) Based on an average of 9,400 miles per year.

▧ Federal control coverage

▨ California control coverage

To identify candidate retrofit devices for used car emission control, specific criteria or standards should be set. To be considered as a candidate for use, a retrofit device would then have to meet those criteria, which should include:

a. Cost limit for initial purchase and installation.

b. Cost limit for recurring maintenance and operation.

c. Emission reduction effectiveness requirement.

d. Reliability requirement.

e. Maintainability requirement.

f. Driveability and safety requirements.

g. Development status requirement.

Quantitative limits or measures should be specified for each criterion. As an example, Table 8-2 shows the criteria that have been specified by California for retrofit devices. To be accredited for use in California, a retrofit device has to meet these criteria. These particular criteria are those considered appropriate for the air pollution problems of California. Other States or air quality control regions may require less restricting criteria.

The retrofit study has shown that criteria for driveability, safety, and development status should be included as part of the accreditation requirements, to ensure minimum impact of a device on vehicle performance and human welfare and maximum benefit of emission reduction effectiveness.

8.4 DETERMINING COST EFFECTIVE RETROFIT METHODS

The feasibility of using retrofit devices as a means of controlling emissions from cars that are either partly or totally uncontrolled is determined fundamentally by the effectiveness and the costs of the devices. Effectiveness is determined mainly by the extent to which a device reduces vehicle emissions, without causing unacceptable characteristics in vehicle driving quality and general operating performance or safety. Costs are determined by the initial purchase price of the device, including the cost of installing it on a vehicle, plus the subsequent cost of operating and maintaining the vehicle with the device installed. Operating and maintenance costs are affected by increased or decreased fuel consumption that a device may cause, by the number of times it may fail partly or wholly and have to be repaired or replaced, by the frequency and type of maintenance required, and the consequent cost of labor and materials.

These considerations present many factors which have to be quantified, calculated, and integrated in order to determine the overall performance capability of a device and then to compare that device with others to see which is best for the level of control required. The criteria shown in Table 8-2 also have to be used in this process of evaluation to see whether a device can meet them.

To perform this evaluation, a uniform and orderly analytical methodology is required, as described in Section 3. This methodology incorporates equations for each criterion of evaluation and interrelates them according to their relative attributes to show the net performance effectiveness of a device or its performance versus cost.

Table 8-2. PERFORMANCE PARAMETERS AND EVALUATION CRITERIA

FACTOR	CRITERIA
1. Emission Index Factors	
a. Emission standards (1)	
HC CO NOx	Less than 350 ppm or 4.5 gm/mi Less than 2.0% or 47.6 gm/mi Less than 800 ppm or 3.0 gm/mi
b. Emission baseline	No increase of any pollutant beyond an allowable experimental error (2)
2. Driveability and Safety Index Factors	
a. Safety	No hazardous conditions
b. Critical driveability	No stall on acceleration No hot idle stall No backfire
c. General driveability	Driveability Index less than 1.0 (refer to para. 3.1.5)
3. Cost and Cost-Related Index Factors	
a. Installation cost (including kit)	Less than $85.00, including labor at $12.50 per hour (3)
b. Recurring cost	Less than $15.00 per year ($0.125 per 100 miles) (4)
c. Reliability	At least 50,000 miles of operation before total failure
d. Maintainability	At least 12,000 miles of operation before periodic maintenance is required
e. Availability	Less than 1 repair hour per 12,000 miles of operation (4)

(1) The volume concentration values are the California used car device accreditation standards as specified in California Health and Safety Code Chapter 4, Article 2, paragraph 39107 (refer to Volume IV, Appendix E). These standards are for the 7-mode cold-start test cycle specified in the 1970 Federal Test Procedure (see pertinent comments and cautions in paragraph 5.1 of this volume). The grams per mile (gm/mi) correlated with the above standards were calculated for a 4,000-pound vehicle in accordance with the method set forth in the 1970 Federal Test Procedure. If the evaluator intends to use the 1972 Federal CVS Test Procedure, appropriate used car standards must be established for that test procedure.

(2) In this report, an experimental error of +10% was used.

(3) $12.50 per hour based on California repair labor average.

(4) Average miles driven per year assumed to be 12,000 miles.

This methodology can be implemented by means of a computer program, if the number of devices to be evaluated justifies that convenience. Otherwise, the methodology can be used manually. A sample manual calculation is shown in Volume I. The computer program approach is discussed in Volume IV.

Use of the analytical methodology systematically derives quantitative indices of the emission reduction, driveability, and cost performance of a device. Since the indices for different devices are all derived uniformly, they can be compared with each other to see which offers the optimum performance for the level of control required. In this way, each candidate device can be screened, so that the most feasible for the intended application can be selected objectively.

8.5 DEFINING THE CERTIFICATION PROGRAM

With the selection of the most feasible retrofit devices by means of the analytical process described above, the development or production sources of the devices would be contacted to determine whether production quantities are ready for mass application. If the analytical evaluation shows doubt in the suitability of a device for certain performance factors, then an accreditation program may be required to verify that the device is indeed feasible.

Certification to prescribed criteria may be required as a matter of standard practice, even though analysis indicates the device to be entirely satisfactory. Considering the cost of implementing and enforcing a retrofit program and the large segment of the public inevitably affected, accreditation of a device prior to its widespread application is the only practical way of obtaining reasonable assurance that a retrofit program will succeed. Such a program is required in particular if competing devices are obtainable.

The certification program should be tailored to the requirements of the retrofit application. In this respect, all requirements or criteria that a device must meet are relative to the retrofit application. The basic question is how much emission reduction effectiveness is required? The retrofit method study has shown that emission reduction effectiveness is generally proportional to the cost of a device; hence the more effectiveness required, in general, the higher the cost will be.

The basic elements of an accreditation program include:

a. Establishing performance criteria which the retrofit device must meet, in terms of emission reduction, driveability, safety, reliability, maintainability, and cost, as shown by the typical examples in Table 8-2.

b. Establishing the sample size which must be tested to demonstrate compliance with the performance criteria. Statistical analysis requirements should be included to determine the required test vehicle sample size needed to establish the validity of the test data.

c. Defining the test procedures that must be followed.

d. Defining the requirements for marketing the accredited device.

e. Defining the requirements for maintaining quality control of the device in use.

Understandably, a retrofit device developer or producer will want to accredit his device for use; however, he must have assurance that a reasonably long term economic incentive exists. Accordingly, the certification program should identify the vehicle population to which the device would be applied, and have provisions for assuring that capital investment risk is minimum.

8.6 COST EFFECTIVENESS STUDIES OF ALTERNATIVE CONTROL PROGRAMS

While the retrofit study has shown that use of the retrofit method of vehicle emission control is a feasible way of reducing emissions from uncontrolled vehicles, it may not be the most optimum method of controlling all vehicle emissions. Alternative methods such as periodic vehicle inspection and transportation controls may actually be more cost effective. For example, routing of main highway arteries through regions of high pollution potential might be more cost effective than controlling vehicle emissions in some cases; or controlled vehicle access to certain geographic areas might be a more feasible alternative. Stringent regulation of uncontrolled vehicles to force their "early retirement" is another possibility. A combination of the retrofit approach with these alternatives is still another possibility.

All possible alternatives should be analyzed before a commitment is made to initiate the retrofit approach to vehicle emission control. Each alternative would have to be defined in detail and perhaps tested in order to develop the data by which to evaluate effectiveness and costs objectively. The analytical methodology developed through this study serves as a guideline for the development of the special analytical techniques that may be needed to evaluate these alternatives.

Cost effectiveness considerations should not deter a program, however, if the pollution hazard to health and welfare in a particular region is critical.

8.7 PREPARING AN IMPLEMENTATION PLAN

A detailed plan is required to control the implementation of the retrofit approach and to maintain and enforce the use of retrofit devices. This detailed plan will be a part of the overall State implementation plan required by the Clean Air Amendments Act of 1970. The plan will provide the basic means of management control for the implemented system. The principal elements of this plan should include:

a. The performance criteria which the retrofit system meets.

b. The vehicle population to which the system is applicable.

c. The plan and schedule for applying the system to these vehicles.

d. Provisions for certifying garages and mechanic personnel to install and inspect the retrofit system.

e. Provisions for training inspector and mechanic personnel.

f. Provisions for monitoring the performance of the installed system to verify that its emission reduction effectiveness is being achieved.

g. Provisions for overall management control and administration of the retrofit program.

h. The financial plan for supporting the retrofit program throughout its life.

These implementation planning requirements divide into two basic areas: (1) those concerning the initiation of the retrofit system on the vehicle population of concern; and (2) those concerning continued monitoring and surveillance of the program. Accrediting and initiating use of a retrofit system is a major segment of activity requiring technical and management specialists for successful accomplishment. Continued surveillance and inspection of the program in operation is a segment of activity of equal importance requiring quality control, as well as technical and management specialists. Periodic inspection of the installed retrofit system would be essential to ensure that the cost effectiveness of the emission control system is being attained in day to day operational use.

8.8 IMPLEMENTING THE PLAN

A formally chartered agency within the State should be established to carry out the plan of implementation, and to provide continued surveillance of retrofit system cost effectiveness. The implementation and management of a sound retrofit plan must be effective, if the calculated reduction in vehicle emissions is to be realized. This is the enforcement phase of the program, wherein the several millions of uncontrolled vehicles are brought under control by the enforcement agency. As indicated by the requirements discussed above, this phase implies controlling the developers, the vehicle repair personnel, and the many vehicle owners. A task of such a magnitude requires that the preparations described in the previous steps be performed with careful deliberation and thoroughness.

Of further consideration in the establishment and implementation of a viable retrofit program is that the above steps not only consider the present time and circumstances, but that all the predictable variations that could occur in the future years be recognized and accommodated in the program. A continuing program should be instituted which provides a periodic evaluation of the air quality problem and the effectiveness of the program. The type of quality control program required to implement and sustain use of retrofit devices is illustrated by that used in California for the installation, adjustment, servicing, inspection, and certification of vehicle pollution control equipment (Reference 15). This program specifies inspection requirements to be followed in the certification of emission controlled vehicles upon change of ownership. Inspection stations are licensed by the State, and Class A pollution control device installer certification is required of inspection personnel. A Class A installer has to be experienced in major automotive tuneup, with optional instruction from an approved school. Applicants must pass an examination before certification is granted. Quality controls of equivalent rigor are considered essential requirements of any program based on use of retrofitted vehicle emission control devices as a means of achieving air quality standards.

Figure 8-1 shows the type of management structure recommended for a periodic vehicle emission inspection program in California (Reference 7). The recommendation of the Reference 7 study was to combine administration and management of Class A stations and State-operated inspection facilities under a single program management agency within the State government. This agency would be organized to provide overall

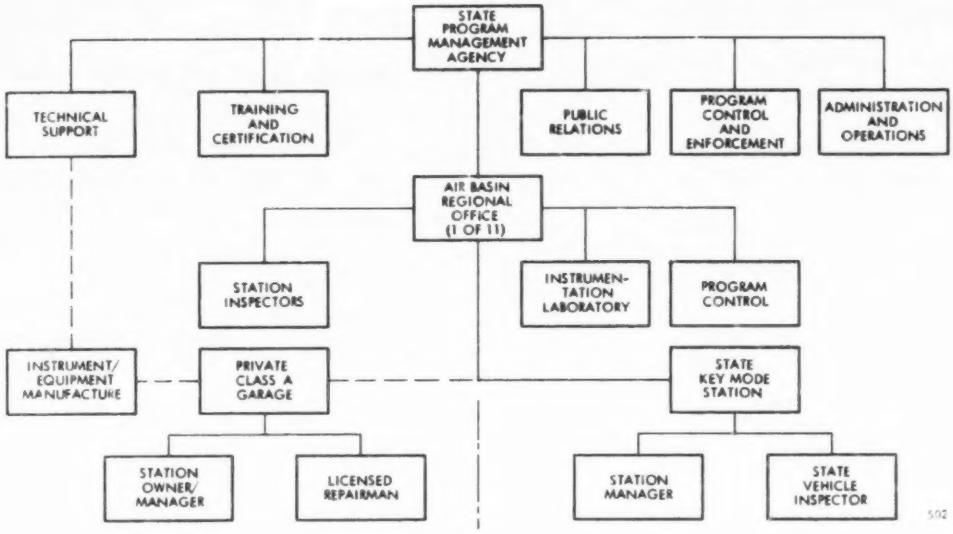

STATE PROGRAM MANAGEMENT AGENCY
TECHNICAL SUPPORT
TRAINING AND CERTIFICATION
PUBLIC RELATIONS
PROGRAM CONTROL AND ENFORCEMENT
ADMINISTRATION AND OPERATIONS
AIR BASIN REGIONAL OFFICE (1 OF 11)
STATION INSPECTORS
INSTRUMENTATION LABORATORY
PROGRAM CONTROL
INSTRUMENT/ EQUIPMENT MANUFACTURE
PRIVATE CLASS A GARAGE
STATE KEY MODE STATION
STATION OWNER/ MANAGER
LICENSED REPAIRMAN
STATION MANAGER
STATE VEHICLE INSPECTOR
502

Figure 8-1. TYPICAL EXAMPLE OF PROGRAM MANAGEMENT STRUCTURE FOR PERIODIC VEHICLE INSPECTION PROGRAM (REFERENCE 7)

program management, with directly reporting regional management offices in each of the 11 California air basins.

The organization chart shown in Figure 8-1 presents the overall management control structure and that of a representative regional office. One State Program Management Agency, through an administrator, would be responsible for planning and managing the program. The State Program Management Agency would be responsible for the overall coordination and control of the program through the five functions shown. This responsibility would include specification of the inspection test regime, implementation, planning and scheduling, training and licensing of inspection and repair stations and personnel, overall program cost and schedule control, and general administration. The agency would also be responsible for establishing the exhaust emission failure limits for the pollutants of concern, the number of vehicles that may be tested annually, the policy on vehicle retest after service, and the requirements that vehicle owners and repair garages must meet should a vehicle fail the second emission test. The program office would also be responsible for establishing and maintaining liaison with other State and local agencies which interface with the program.

Regulation of Class A stations and State-operated stations would be delegated to the regional offices.

This management structure, by consolidating management and control of privately operated licensed stations and State-operated stations under a single responsible agency, should enable uniform achievement of performance standards among all participants. The standardization of management systems and procedures thereby achieved should provide efficiency and economy in operations throughout the life of the program.

SECTION 9

RECOMMENDATIONS

The following programs are recommended as future research and development efforts in support of retrofit method implementation.

1. The applicability of retrofit methods to vehicles factory equipped with emission control techniques should be studied as a means of achieving maximum usefulness of the retrofit approach. An example of this recommendation would be to retrofit and evaluate NOx type control devices on 1966 through 1970 model cars in California and 1968 through 1972 vehicles elsewhere in the nation.

2. The maintenance requirements of the cost effective retrofit devices will require that provisions for a maintenance inspection program be planned and implemented concurrent with the promulgation of any legislation requiring the use of retrofit devices on a mandatory basis. A study should be implemented to determine the procedures, criteria, personnel, instrumentation, facility, and training requirements of a maintenance inspection program to support any mandatory use of retrofit devices. This program would be designed to ensure that the inherent cost effectiveness of a retrofit device is not compromised by inattention to the maintenance requirements of the device.

3. Upgrading of the automotive service industry through supplemental training programs would be required to provide correct tuneup adjustments to vehicles with retrofit devices installed. The scope and requirements of such upgrading should be studied and specified for the principal types of devices. The cost impact of an upgraded service industry on the cost effectiveness of retrofit devices should also be determined.

SECTION 10

REFERENCES

1. Contract EPA 68-04-0038, Analysis of Effectiveness and Costs of Retrofit Emissions Control Systems for Used Motor Vehicles, dated 30 June 1971.

2. Estimated by Olson Laboratories, Inc. from Data in Project Clean Air Research Report, Project S-10, Research Reports, Volume 3, University of California. (See Reference 14.)

3. "Control Techniques for CO, NO_x, and HC - Mobile Sources," AP-66, March 1970, issued by HEW/NAPCA.

4. 1972 Test Procedures for Vehicle Exhaust (Gasoline Fueled Light Duty Vehicles), Subpart H of Part 1201, Chapter XII, Title 45 Code of Federal Regulations, as published in the Federal Register, Volume 35, Number 219, Part II, 10 November 1970. (See Reference 11 for NOx procedure.)

5. 1970 Federal Test Procedure, The Federal Register, Volume 33, Number 108, Part II, 4 June 1968.

6. EPA Interim Constant-Volume-Sampling Test Procedure Based on Nine Cycles of the Cold-Start 1970 Federal 7-Mode Test Procedure (Telecon 25 April 1972 from W. R. Hougland, EPA Project 68-04-0038 Documentation Task Leader, to Ralph Stahlman, EPA Office of Air Programs, Division of Emission Control Technology, Test Branch).

7. Northrop Corporation Electro-Mechanical Division in association with Olson Laboratories, Inc., "Mandatory Vehicle Emission Inspection and Maintenance," Part A Feasibility Study Final Report, Contract ARB 1522 (California Air Resources Board), Northrop Report No. 71Y110 (four volumes), 21 June 1971.

8. Northrop Corporation Electro-Mechanical Division in association with Olson Laboratories, Inc., "Mandatory Vehicle Emission Inspection and Maintenance," Part B, Test Program Final Report, Contract ARB 1522 (California Air Resources Board), Northrop Report No. 71Y240A (two parts), 10 December 1971.

9. Ann,"Math Statistics," 21, 488 (1950); 22. 68 (1951).

10. See Lord, Biometrika 37, 64 (1950), Pearson and Harley, ibid 38, 112 (1951) B. L. Welch, ibid 34, 28-35, January (1947).

11. Test Procedures for NOx Evaluation, The Federal Register, Volume 36, No. 128, Part II, 2 July 1971.

12. California Health and Safety Code, Chapter 4, Article 2, paragraph 39107 (refer to excerpts in Volume IV, Appendix E).

13. R. A. Fisher,"Fiducial Argument in Statistical Inference," Annals of Eugenics, 6, 391-8, December 1935.

14. Downing, Paul B., and Lytton Stoddard, "Benefit/Cost Analysis of Air Pollution Control devices for Used Cars," Project Clean Air Research Project No. S-10, University of California, September 1970.

15. California Highway Patrol, "Handbook for Pollution Control Device Installation and Inspection," Document HPH 82.1, April 1971.

16. State of California Air Resources Board, "California Exhaust and Fuel Evaporative Emission Standards and Test Procedures for Used Motor Vehicles under 6,001 Pounds Gross Vehicle Weight," dated 20 November 1968.

APPENDIX A

BASELINE EXHAUST EMISSIONS FOR TEST VEHICLES PRIOR TO EACH RETROFIT TEST (1972 FEDERAL TEST PROCEDURE GRAMS/MILE)

CAR NUMBER	HYDROCARBON TESTS								
	1	2	3	4	5	6	7	8	9
Anaheim									
1	(1)	15.10	9.05(5)	11.09	10.67	8.12			
2	6.53	8.81	6.59	8.85	11.61(5)	10.36	10.55		
3	6.12	5.49	6.12	4.77(5)	6.62	10.55	7.06		
4	6.15	7.06	8.66	5.28	9.17	8.80	7.98	6.70	7.92
5	14.14	(3)	8.35	8.00	6.73	8.35	8.37		
6	(1)	(4)	4.54	6.33	7.47	5.65	5.57	5.87(5)	
17	10.88								
18	(1)								
19	10.81	7.79							
21	9.06(6)								
22	7.91(6)								
Detroit									
8	3.69	5.36	4.15	3.06	3.59	3.69			
9	6.02	4.94	4.63	3.38	3.46	4.04			
10	3.95	7.68	5.98	4.70	4.63	4.68			
11	7.61	7.36	8.66	5.33	4.08	3.43			
12	8.17	8.07	6.45	5.27	3.55	4.36			
16	5.18								
20	6.12	5.32							

CAR NUMBER	CARBON MONOXIDE TESTS								
	1	2	3	4	5	6	7	8	9
Anaheim									
1	202.99	135.37	92.40(5)	85.06	71.56	75.39			
2	73.65	106.46	117.45	121.83	137.14(5)	149.77	181.80		
3	94.73	69.55	83.70	56.79(5)	101.94	133.27	68.90		
4	66.49	61.86	59.29	62.86	66.67	69.76	53.65	75.96	80.01
5	150.50	(3)	109.86	88.37	74.88	111.73	104.45		
6	72.39	(4)	70.78	89.96	77.44	72.81	(1)	85.59(5)	
17	163.37								
18	85.86								
19	76.12	51.78							
21	92.11(6)								
22	64.95(6)								
Detroit									
8	38.40	55.78	57.96	83.54	59.16	57.16			
9	97.62	69.81	39.88	43.38	46.50	56.10			
10	52.52	74.87	42.04	45.56	43.65	40.82			
11	125.34	99.55	109.96	89.38	64.45	50.91			
12	72.41	72.94	56.03	55.71	36.34	38.52			
16	46.82								
20	37.50	34.11							

APPENDIX A

BASELINE EXHAUST EMISSIONS FOR TEST VEHICLES PRIOR TO EACH RETROFIT TEST (1972 FEDERAL TEST PROCEDURE GRAMS/MILE) (CONCL)

CAR NUMBER	OXIDES OF NITROGEN TESTS								
	1	2	3	4	5	6	7	8	9
Anaheim									
1	0.65	0.84	2.01(5)	2.87	2.20	1.72			
2	4.45	4.60	3.28	2.83	2.41(5)	1.29	1.02		
3	5.93	5.14	5.74	6.81(5)	3.33	3.00	3.24		
4	3.25	3.35	4.45	3.37	3.46	2.87	2.49	1.95	[illegible].32
5	3.72	(3)	2.32	3.49	1.90	2.19	2.56		
6	2.92	(4)	2.39	2.19	1.82	1.72	1.29	2.20(5)	
17	3.16								
18	1.46								
19	1.69	1.57							
21	3.68(6)								
22	3.65(6)								
Detroit									
8	3.24	4.53	3.84	6.12	2.61	3.87			
9	4.29	5.77	5.48	3.87	4.34	3.79			
10	(1)(2)	6.88	5.10	3.42	5.14	3.82			
11	4.12	3.48	3.20	2.86	2.83	2.34			
12	3.42	3.34	2.75	2.56	3.28	2.88			
16	5.03								
20	2.18	1.75							

(1) Test data invalid.
(2) Data outlier, see text paragraph 4.2.1.4
(3) Baseline for test number 2 invalid due to blown head gasket.
(4) Baseline test not performed.
(5) Data not used due to incomplete test.
(6) Baseline tests for Durability Program.

APPENDIX B-1

RETROFIT PROGRAM TEST SCHEDULE

CAR NO.	MAKE (CID)	WEEK OF OCT 11, 71	OCT 18	OCT 25	NOV 1	NOV 8	NOV 15	NOV 22	NOV 29	DEC 6	DEC 13	CAR NO.
1	ANAHEIM											
1	65 CHEV 194	-	-	246	1	-	96	96 (R)	175	-	-	1
2	65 FORD 289	1	246	-	288	-	-	96	-	96 (R)	33	2
3	65 PLYM 318		246	69	1	-	69 (R)	96	175	96 (R)	-	3
4	65 CHEV 327	42	246	69	1	10	96	96 (R)	175	-	33	4
5	65 FORD 390	42	-	-	1	295	69	96	175	96 (R)	-	5
6	61 CHEV 283	1	245	288	-	10	96	96 (R)	175	-	-	6
17	65 FORD 390	-	246	-	-	BL(M)	1 (M)	246 (M)	96 (M)	175 (M)	175 (D)	17
18	61 CHEV 283	-	-	-	-	-	246(D)	-	-	-	-	18
19	65 VW 92	-	-	-	-	-	-	-	-	1	246	19
21	65 CHEV 327	-	-	-	-	-	-	-	-	-	96 (D)	21
22	65 CHEV 327	-	-	-	-	-	-	-	-	-	96 (D)	22
2	DETROIT											
8	65 FORD 289	-	-	-	246	1	1 (R)	246 (R)	96	175	-	8
9	65 PLYM 318	-	-	-	246	1	1 (R)	246 (R)	96	175	-	9
10	65 CHEV 327	-	-	-	246	1	1 (R)	246 (R)	96	175	-	10
11	65 FORD 390	-	-	-	246	1	1 (R)	246 (R)	96	175	-	11
12	61 CHEV 283	-	-	-	246	1	1 (R)	246 (R)	96	175	-	12
14	65 FORD 289	-	-	-	-	-	-	-	-	-	-	14
15	65 PLYM 318	-	-	-	-	-	-	-	-	-	-	15
16	65 CHEV 327	-	-	-	-	-	-	-	-	175	-	16
20	65 VW 92	-	-	-	-	-	-	-	-	1	246	20
												TOTAL TESTS
Replicate Tests (R)		0	0	0	0	0	6	8	0	3	0	17
Total Evaluations		4	5	4	10	8	12	11	10	9	2	75
Mountain & Desert (M)		0	0	0	0	1	1	1	1	1	0	5
Durability Tests (D)		0	0	0	0	0	1	0	0	1	3	5

Total Level 1, 2 and 2 Replicate
*Dashes indicate that vehicle was not scheduled for tests.
*BL is Baseline without device.

APPENDIX B-2

RETROFIT PROGRAM TEST SUMMARY VERSUS CONTRACT REQUIREMENTS

TEST DESCRIPTION	TESTS ACTUALLY PERFORMED	EPA CONTRACT 68-04-0038 REQUIREMENTS
1. Number of different devices	11	6
2. Number of vehicles	20	24 (Maximum required)
See Table 4.1	5	
3. As received tests		12
72 Federal Procedure Emission Tests	13	12
7-Mode	16	12
4. Tuneup		
Auto Manufacturer's Specifications	20	20
5. Baseline emission & driveability	75 Total	72 (Maximum required)
Replicate (included in 75 total)	17	
6. Retrofit emission & driveability	75 Total	72 (Maximum required)
Replicate (included in 75 total)	17	
7. Mountain and desert tests	5	5
Baseline Driveability	1	
Retrofit Driveability	4	
8. Durability emission test, 72 Federal Procedure	67	24
0 Miles (without device)	5	5
0 Miles (device installed)	5	4
5,000	5	4
10,000	5	4
15,000	6	4
20,000 (with device)	14	4
20,000 (without device)	1	
25,000 (with device)	14	4
25,000 (without device)	12	

APPENDIX C

DEVICES EVALUATED IN RETROFIT PROGRAM

DEVICE	DEVICE TITLE	PURPOSE	GROUP
1 (1) (2)	Air Bleed to Intake Manifold: Air bleed to intake manifold through adjustable valve open to ambient airflow.	Lean air-fuel mixture.	1.2.1
10 (2)	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect: Carburetor fuel vaporization modification, combined with throttle-position controlled exhaust gas recirculation through intake manifold; and with temperature-controlled vacuum advance disconnect.	Improve air-fuel diffusion, lower combustion temperatures and increase exhaust gas oxidation.	1.2.2
22 (1)	Electronic Fuel Injection: Electronically regulated fuel injection.	Optimize air-fuel mixing.	1.2.6
23 (1)	Electronic Ignition Unit: Electronic modification to coil.	Enhance combustion ignition.	1.3.2
24 (1)	Heavy Duty Positive Crankcase Control Valve with Air Bleed: Crankcase blowby gas control with air dilution.	Recirculate unburned HC and exhaust gas from crankcase for combustion with lean air-fuel mixture.	2.1
31	Thermal Reaction by Turbine Blower Air Injection: Air injection into conventional exhaust manifold by means of air turbine operating off intake vacuum.	Oxidize unburned HC and CO combustion byproducts in exhaust gas.	1.1.2
33 (2)	Carburetor Modification, Main Jet Differential Pressure: Carburetor fuel bowl vented to intake manifold rather than atmosphere by means of tubing with adjustable valve.	Lean air-fuel mixture at high intake manifold vacuum during idle and deceleration.	1.2.4
36 (1)	Fuel Conditioning by Exposure to Electromagnetic Field: Intake fuel routing through magnetic field.	Condition fuel prior to entering carburetor.	1.4.3
42 (2)	Air Bleed to Intake Manifold: Air bleed from air cleaner to intake manifold through tubing with adjustable valve.	Lean air-fuel mixture	1.2.1
52 (1) (3)	LPG Conversion: Liquified petroleum gas (LPG) conversion.	Decrease pollutants by use of lower reactivity, cleaner burning gaseous fuel.	1.4.1
56	Crankcase Blowby and Idle Air Bleed Modification: Heated air bleed through special idle jets, combined with heated crankcase blowby into intake manifold.	Lean air-fuel mixture in combination with blowby control.	1.2.4
57	Air Bleed with Exhaust Gas Recirculation and Vacuum Advance Disconnect: Bleeds combination of exhaust gas and filtered ambient air to intake manifold, with temperature-controlled distributor vacuum advance disconnect.	Lean air-fuel mixture in combination with exhaust gas recirculation to reduce combustion temperature and retarded timing to increase exhaust gas oxidation.	1.2.1
59	Three-Stage Exhaust Gas Control System: (4)	Combustion byproduct control in exhaust system.	4.0
62 (1)	Catalytic Converter: Replaces standard muffler.	Oxidize unburned combustion byproducts in the exhaust system.	1.1.1
69 (2)	Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification: Electronic control of distributor vacuum advance during idle through 1,600 rpm and during braked deceleration with temperature-controlled override and lean air-fuel mixture by modifying air screws.	Lean air-fuel mixture combined with retarded timing to increase exhaust gas oxidation.	1.3.1
93 (1)	Catalytic Converter with Exhaust Gas Recirculation, Spark Modification, and Lean Idle Mixture: Catalytic reactor with air pump and exhaust gas recirculation, plus special ignition system and lean air-fuel mixture.	Improve oxidation of combustion byproducts and reduce combustion to inhibit NOx formation.	1.1.1
95 (1)	Ignition Spark Modification: Fits between spark plug leads and distributor.	Pre-condition combustion chamber gases in preparation for ignition event.	1.3.2

APPENDIX C

DEVICES EVALUATED IN RETROFIT PROGRAM

DEVICE	DEVICE TITLE	PURPOSE	GROUP
96 (1) (2)	Catalytic Converter with Distributor Vacuum Advance Disconnect: Catalyst contained in canister installed between exhaust manifold and muffler, combined with distributor vacuum advance disconnect, and/or air injection by special pump.	Oxidize unburned combustion byproducts by catalyst action and higher exhaust temperature. Reduce NOx by reduced peak cycle combustion temperature.	1.1.1
100 (1)	Turbocharger: Exhaust gas driven turbocharger.	Improve fuel oxidation during low intake vacuum by forced air injection to carburetor.	1.2.5
160 (3)	Closed or Open Blowby Control System with Filter: Filtered, volumetric-controlled blowby gas recirculation.	Recirculate blowby gas from crankcase to intake manifold for combustion, without impurities.	2.2
164	Exhaust Gas Filter: Two-stage exhaust gas filter with combined muffler function.	Incomplete data precludes full determination of purpose; however, one application appears to be particulate control.	1.1.4
165	Exhaust Gas Afterburner/Recirculation with Blowby and Fuel Evaporation Recirculation: Combined exhaust gas afterburning and recirculation, with crankcase blowby and fuel evaporation.	Control all three major sources of vehicle emissions.	4.0
170 (3)	Closed Blowby Control System: Closed blowby gas recirculation through carburetor air cleaner and intake manifold combination.	To recirculate blowby gas from crankcase to intake manifold for combustion.	2.1
172 (1)	Intake Manifold Modification: Truncated conical nozzles inserted between intake port and intake manifold.	Equalize air-fuel mixture distribution.	1.2.3
175 (2) (3)	Ignition Timing Modification with Lean Idle Adjustment: Electronically controlled ignition spark retardation by sequenced regulation of the distributor ignition signal and the vacuum advance disconnect, combined with lean idle air-fuel mixture adjustment.	Spark retardation at idle and speeds below 35 mph in combination with lean air-fuel mixture.	1.3.1
182	Fuel and Oil Additives: Hydrocarbon-base fuel and oil additive.	Reduce engine deposits and fuel consumption and increase power.	1.4.2
244 (1)	Rich Thermal Reactor: Exhaust manifold replacement providing thermal insulated chamber and air injection.	Oxidize unburned combustion byproducts in exhaust manifold.	1.1.2
245 (2)	Variable Camshaft Timing: Cam timing gear replacement automatically varies valve timing from advance at idle and low rpm to retard at high speeds.	Provide exhaust gas recirculation.	1.2.2
246 (1) (2)	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect: Exhaust gas recirculation through intake manifold adapter controlled by speed-sensitive solenoid valve which also disconnects distributor vacuum advance during low speed modes.	Lower combustion temperature combined with higher temperature exhaust.	1.2.2
259	Photocell-Controlled Ignition System: Ignition spark modification by photo-cell controlled ignition system.	Increase spark duration and eliminate mechanical distributor breaker points.	1.3.2
268	Capacitive Discharge Ignition: Ignition spark modification by high-voltage capacitor discharge to ignition coil primary, operating in series to the distributor and coil.	Modify firing voltage across the spark plugs.	1.3.2
279	Fuel Conditioner: Intake fuel routing through electrical field.	Condition fuel prior to entering carburetor.	1.4.3
282	LP Gas Injection: Propane injection to carburetor air intake during acceleration and engine load conditions, based on intake manifold vacuum.	Addition of lower reactivity, cleaner burning fuel.	1.4.2

APPENDIX C

DEVICES EVALUATED IN RETROFIT PROGRAM

DEVICE	DEVICE TITLE	PURPOSE	GROUP
288 (2)	Carburetor Main Discharge Nozzle Modification: Air jet added to main circuit nozzle outlet.	Enhance air-fuel mixture diffusion.	1.2.4
292 (1)	Catalytic Converter: Platinum catalyst device installed in exhaust pipe.	Oxidize emission byproducts of combustion in the exhaust system.	1.1.1
294 (1)	Exhaust Gas Recirculation with Carburetor Modification: (4)	Optimize air-fuel mixing combined with lower combustion temperatures.	1.2.2
295 (2)	Carburetor with Variable Venturi: Replacement carburetor incorporating variable venturi and fuel nozzle.	Optimize air-fuel ratio and diffusion.	1.2.4
296	Ignition Timing and Spark Modification: Electronically controlled spark retardation by delaying distributor breaker point pulse to coil, combined with longer spark duration, up to mid-rpm range.	Enhance fuel combustion and increase exhaust gas temperature.	1.3.2
308	Exhaust Gas Afterburner: High voltage continous-spark chamber ignites exhaust gas upstream of muffler in exhaust system.	Oxidize unburned byproducts of combustion in exhaust system.	1.1.3
315	Closed Blowby Control System: Crankcase blowby recirculation through intake manifold adapter controlled by accelerator linkage, with air-fuel diffusion fans located in adapter ports.	Mixing of blowby gases prior to entering intake manifold.	2.1
317	Carburetor Modification with Vacuum Advance Disconnect: Combination air-fuel bypass from carburetor to intake manifold, based on intake vacuum and valve metered flow, combined with vacuum advance disconnect during acceleration.	Reduce combustion temperature and increase exhaust gas temperature for improved oxidation of unburned combustion byproducts.	1.2.4
322 (1)	Exhaust Gas Backpressure Valve: Backpressure flapper valve installed on end of exhaust pipe.	Apply backpressure on the exhaust system.	1.1.5
325	Air-Vapor Bleed to Intake Manifold: Water-alcohol-air-vapor bleed to intake manifold through adapter plate with air bleed during idle and crankcase blowby recirculation.	Leaner air-fuel mixture.	1.2.1
384	Air-Fuel Mixture Diffuser: Two-layer, conical wire screen air-fuel diffuser.	Improve air-fuel mixing and conditioning for combustion.	1.2.3
401	Air-Vapor Bleed to Intake Manifold: Metered water-alcohol-air vapor bleed to intake manifold from container.	Leaner air-fuel mixture.	1.2.1
408	Exhaust Gas and Blowby Recirculation with Intake Vacuum Control and Turbulent Mixing: Exhaust gas recirculation combined with crankcase blowby recirculation to intake manifold with vacuum actuated valving and turbulent mixing.	Blowby control and lower combustion temperature.	4.0
418 (1)	Air Bleed to Intake Manifold: Air bleed to intake manifold through crankcase blowby recirculation line.	Lean air-fuel mixture.	1.2.1
425	Exhaust Gas Afterburner: Exhaust gas afterburner operating with rich air-fuel ratio and air injection.	Oxidize unburned byproducts of combustion.	1.1.3
427	Closed or Open Blowby Control System with Filter: Closed- or open-system crankcase blowby recirculation to intake manifold with blowby filtering.	Recirculate filtered blowby gases for combustion.	2.1/2.2

APPENDIX C

DEVICES EVALUATED IN RETROFIT PROGRAM

DEVICE	DEVICE TITLE	PURPOSE	GROUP
430	Induction Modification: Conical screen insert between carburetor and intake manifold.	To diffuse air-fuel mixture.	1.2.3
433	Air-Vapor Bleed to Intake Manifold: Exhaust gas afterburner operating with lean air-fuel ratio and air injection.	Oxidize unburned byproducts of combustion.	1.2.1
440	Air-Fuel Mixture Deflection Plate: Shaped deflection plate insert between carburetor and intake manifold.	To diffuse air-fuel mixture.	1.2.3
457 (1)	Water Injection: Water-alcohol-air vapor injection to intake manifold.	Oxidize unburned byproducts of combustion.	1.4.2
458 (1)	Air Bleed to Intake Manifold: Air-vapor injection to intake manifold through positive ventilation line.	Oxidize unburned byproducts of combustion.	1.2.1
459 (1) (3)	LPG Conversion with Deceleration Unit: Liquified petroleum gas (LPG) carburetor conversion with deceleration throttle control device.	Decrease pollutants by use of lower reactivity, cleaner burning LPG; combined with delayed throttle closure during deceleration, to enhance combustion of residual fuel in the intake manifold.	1.4.1
460 (1) (3)	Compressed Natural Gas Dual-Fuel Conversion: Dual-fuel conversion enabling use of compressed natural gas or gasoline.	Decrease pollutants by use of lower reactivity, cleaner burning natural gas during high-emission-potential driving modes.	1.4.1
461 (1)	LPG Conversion with Exhaust Reactor Pulse Air Injection and Exhaust Gas Recirculation: Liquified petroleum gas conversion with exhaust reactor, exhaust gas recycle, and pulse air injection to reactor.	Decrease pollutants by use of lower reactivity, cleaner burning gaseous fuel combined with oxidation of combustion byproduct.	1.4.1
462 (1)	Air Bleed to Intake and Exhaust Manifolds: Air bleed to intake manifold through crankcase blowby recirculation line, with exhaust dilution by air bleed.	Lean air-fuel mixture.	1.2.1
463 (1)	Rich Thermal Reactor with Exhaust Gas Recirculation and Spark Retard: Replacement exhaust manifold.	Oxidize combustion byproducts in the exhaust system, while lowering combustion temperature to inhibit NOx.	1.1.2
464 (1)	Methanol Fuel Conversion with Catalytic Converter: Engine conversion for operation on methanol fuel, combined with exhaust gas oxidation by catalytic reaction, plus exhaust gas recirculation option.	Decrease pollutants by use of lower reactivity, cleaner burning fuel and catalytic oxidation of exhaust gas.	1.4.1
465 (1)	Fuel Additive: Bycosin fuel additive.	To enhance combustion efficiency.	1.4.2
466 (1) (3)	LPG-Gasoline Dual-Fuel Conversion: Dual-fuel conversion enabling use of liquified petroleum gas or gasoline.	Decrease pollutants by use of lower reactivity, cleaner burning natural gas during high-emission-potential driving modes.	1.4.1
467	Fuel Evaporation Control System: Fuel evaporation control by carbon canister storage.	Control fuel evaporation from fuel tank and carburetor.	3.0
468	Lean Thermal Reactor with Exhaust Gas Recirculation: Reactor air supplied by lean air fuel mixture with recirculation of oxidized exhaust gas.	Oxidize combustion byproducts and provide lower combustion temperatures, plus particulate control.	1.1.2
469 (1)	Rich Thermal Reactor with Exhaust Gas Recirculation and Particulate Control: Replacement exhaust manifold (thermal reactor) with recirculation of oxidized exhaust gas and particulate trapping.	Oxidize combustion byproducts and provide lower combustion temperatures, plus particulate control.	4.0

(1) Previously tested by EPA.
(2) Tested in retrofit program.
(3) Accredited for use in California. In the case of Device 459, accreditation does not refer to the deceleration control unit.
(4) System description data not available.

APPENDIX D

PERFORMANCE ANALYSIS INPUT DATA

This appendix presents all of the input data to the performance analysis computer program. Table D-1 begins with a listing of basic constants, such as the evaluation criteria, used to exercise the data program. These are self-explanatory. Listed next are the values used for the emission weighting factors β_{HC}, β_{CO}, and β_{NOx}. These values are followed by the driveability coefficient values α_1 to α_{16} and the weighting factors, C_i, used in calculation of the Performance Index.

The device input data are listed across the page for each of the 11 laboratory tested devices. Reading from left to right:

	DATA ITEM	EXAMPLE VALUE
1.	Emission standards met	5.
2.	No input	0.
3.	Safety factor established	1.
4.	Mean-miles-before-total-failure of device, miles	75,000.
5.	Mean-time-to-repair, hours	0.50
6.	Mean-miles-before-maintenance, miles	12,000.
7.	Mean-time-to-maintain, hours	0.30
8.	Mean-miles-before-partial-failure	50,000.
9.	No input	0.
10.	Repair part cost, dollars	14.50
11.	Maintenance part cost, dollars	2.50
12.	Retail cost, dollars	48.00
13.	Installation time, hours	1.25
14.	Device adapter cost, dollars	0.00
15.	No input	0.
16.	No input	0.
17.	Percentage of population covered, %	90.00
18.	No input	0.
19.	No input	0.
20.	Device identification number	1.

A more detailed explanation of the field descriptions is presented in the following paragraphs.

Table D-2 lists the emission and driveability test data for the 11 devices laboratory tested. The emission test data cards are read in pairs; A and B followed by the driveability test associated with that emission test. It should be noted that the "as received" emission tests were not accompanied by a driveability test.

To explain the data format in Table D-2, the first two cards (A and B) listed are used (entry characters are right justified within their fields unless constrained by a fixed decimal point). Each card represents a line of information.

FIRST CARD (A):

FIELD CHARACTER(S)	ITEM	EXAMPLE VALUE
1	Card identifier	A
2-11	Vehicle number - XXXYYY XXX - 360 = Anaheim - 706 = Taylor YYY = Test vehicle ID number	360001
12-13	Month of test	10
14-15	Day of test	23
16-17	Year of test	71
18-19	Wet bulb reading, °F	61
20-21	Dry bulb reading, °F	75
22-26	Barometric pressure, in. Hg	30.01
27-45	Not used	blank
46-51	Run number	204088
52-57	CVS unit number	408-08
58-61	Not used	blank
62-65	Test identifier 001 = As received XXX2 = Baseline test XXX3 = Retrofit test	001

SECOND CARD (B):

FIELD CHARACTER(S)	ITEM	EXAMPLE VALUE
1	Card identifier	B
2-3	Not used	blank
4-9	Run number	204088
10-12	Inlet temperature, °F	111
13-17	Inlet pressure, in. Hg	3.0
18-22	Not used	blank
23-27	Volume per revolution	.3060
28-32	Revolutions count	28364
33-37	Weight of fuel consumed, lbs.	2.25
38-41	Sample of HC, ppm	817
42-46	Sample CO, ppm	3640
47-50	Not used	blank
51-54	Sample NOx, ppm	12
55-57	Background HC, ppm	26
58	Not used	blank
59-63	Background CO, ppm	180
64-67	Not used	blank
68-71	Background NOx, ppm	0000

The driveability test data follows the "B" card unless the emission test is an "as received" test for which no driveability test was performed. The data fields are separated by a blank space on the printout and give the test values for:

1. Test identifier (same as Card A characters 62-65)
2. Average cold cranking time
3. Number of attempts to start cold vehicle
4. Rough idle cold
5. Cold idle stall
6. Stall on cold acceleration
7. Backfire on cold acceleration
8. Stumble on cold acceleration
9. Hesitation on cold acceleration
10. Detonation on cold acceleration
11. Stretchiness on cold acceleration
12. Surging on cold acceleration

13,14 Not used

15. Average hot cranking time
16. Number of attempts to start hot vehicle
17. Rough idle hot
18. Hot idle stall
19. Stall in hot drive modes
20. Backfire in hot drive modes
21. Stumble in hot drive modes
22. Hesitation in hot drive modes
23. Detonation in hot drive modes
24. Stretchiness in hot drive modes
25. Surging in hot drive modes

26-28 Not used

29. 0-60 mph acceleration time in seconds
30. 60-40 mph deceleration time in seconds

As in Table D-1 the device data fields in Table D-3 are listed across the page in the following order for each of the 11 devices tested in the retrofit program:

FIELD CHARACTERS	DESCRIPTION
1-4	Retrofit Device Identification Number
5,6	STDS: Claimed emission standard met: 1 = HC and CO 2 = HC and NOx 3 = CO and NOx 4 = HC,CO, and NOx 5 = HC 6 = CO 7 = NOx
7,8	No input
9,10	SAF: Safety factor: 1 for device considered safe 0 for device considered unsafe
11-17	MMBTF: Mean-miles-before-total-failure of the device, in miles.
18-21	MTTR: Mean-time-to-repair device failure, in hours.
22-28	MMBM: Mean-miles-before-maintenance, in miles.
29-32	MTTM: Mean-time-to-maintain, in hours.
33-39	MMBPF: Mean-miles-before-partial-failure of device, in miles.

FIELD CHARACTERS	DESCRIPTION
40-42	No Input
43-47	REPAIR PART COST, in dollars
48-52	MAINT PART COST, in dollars
53-58	RETAIL COST, in dollars
59-62	INST TIME, in hours
63-67	ADPTR COST, in dollars
68-74	No Input
75-79	Coverage, population covered, in %
80	No Input

Table D-3 itemizes the cost-related data for the devices evaluated. Table D-3 follows the same format as Table D-1.

Table D-1. PERFORMANCE ANALYSIS DATA RUN BASIC CONSTANTS

```
THE CONSTANTS USED FOR THIS RUN ARE:

   COMPARISON LIMITS FOR HC,CO, AND NOX IN GM/MI ARE,      4.5    47.6     3.0
   MAXIMUM ALLOWED EMISSION INCREASE FROM BASELINE DUE TO EXPERIMENTAL ERROR, %  10.0
   MAXIMUM DRIVEABILITY INDEX ALLOWED FOR CRITERIA INDEX  1.0
   MINIMUM RELIABILITY ALLOWED, IN MILES  50000.
   MINIMUM AVAILABILITY ALLOWED, IN MI/REPAIR HOUR  12000.
   AVERAGE MILES PER YEAR DRIVEN  12000.
   DEVICE COST LIMIT, INSTALLED  85.  DOLLARS
   HOURLY LABOR RATE, DOLLARS  12.50
   RECURRING COST LIMIT, DOLLARS PER YEAR  15.
   RECURRING COST LIMIT, DOLLARS PER MILE 0.00125
   AVERAGE FUEL COST, DOLLARS PER GALLON 0.350(1)

   THE EMISSION WEIGHTING FACTORS ARE:   1.000   1.000   1.000

   THE DRIVABILITY COEFFICIENT TERMS ARE:
    0.3333 1.6666 0.0083 0.0083 0.5000 0.0083 0.0083 2.0000 0.1000 0.1000 0.1000 0.0500 0.0500 1.0000 1.0000 5.0000

   THE EI, DI, AND CI WEIGHTING FACTORS ARE:   4.000   1.000   2.000

   THE DEVICE DATA FOR DEVICE NUMBER   1
     5.  0.  1.   75000.  0.75   12000.  0.30   75000.  0.  14.50   2.50  48.00  1.25   0.0   0.  0.  90.00  0.  0.    1.
   THE DEVICE DATA FOR DEVICE NUMBER   2
     5.  0.  1.   50000.  0.55   12000.  0.50   50000.  0.  11.00   1.25  55.00  1.25   0.0   0.  0.  90.00  0.  0.   10.
   THE DEVICE DATA FOR DEVICE NUMBER   3
     5.  0.  0.   75000.  1.00       0.  0.0    75000.  0.   8.65   0.0    8.65  1.00   0.0   0.  0.  90.00  0.  0.   33.
   THE DEVICE DATA FOR DEVICE NUMBER   4
     5.  0.  1.   75000.  1.00   12000.  0.20   75000.  0.  10.00   0.0   10.00  1.00   0.0   0.  0.  90.00  0.  0.   42.
   THE DEVICE DATA FOR DEVICE NUMBER   5
     5.  0.  1.   75000.  0.65   12000.  0.30   75000.  0.  23.00   0.0   50.00  1.00   0.0   0.  0.  90.00  0.  0.   69.
   THE DEVICE DATA FOR DEVICE NUMBER   6
     5.  0.  1.   50000.  1.67    8333.  0.27   50000.  0.  35.00  16.25(2)125.00 4.00   0.0   0.  0.  90.00  0.  0.   96.
   THE DEVICE DATA FOR DEVICE NUMBER   7
     5.  0.  1.   75000.  1.00       0.  0.0    75000.  0.  32.00   0.0   32.00  1.00   0.0   0.  0.  90.00  0.  0.  175.
   THE DEVICE DATA FOR DEVICE NUMBER   8
     7.  0.  1.   75000.  2.25   25000.  0.50   75000.  0.  50.00   0.0   50.00  2.25   0.0   0.  0.  90.00  0.  0.  245.
   THE DEVICE DATA FOR DEVICE NUMBER   9
     5.  0.  1.   75000.  0.87    6000.  0.50   75000.  0.  16.00   1.25  61.00  2.25   0.0   0.  0.  90.00  0.  0.  246.
   THE DEVICE DATA FOR DEVICE NUMBER  10
     2.  0.  1.   75000.  1.25       0.  0.0    75000.  0.  25.00   0.0   25.00  1.25   0.0   0.  0.  90.00  0.  0.  288.
   THE DEVICE DATA FOR DEVICE NUMBER  11
     4.  0.  1.   75000.  0.75   12000.  0.50   75000.  0.  40.00   0.0   70.00  0.75   0.0   0.  0.  90.00  0.  0.  295.
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(1) Except Device 96, for which unleaded fuel cost of $0.38/gallon was used.

(2) C_{MP} = \$5.42.

Table D-2. EMISSION AND DRIVEABILITY TEST DATA

```
A    360001102371617530.01                    204088408-08    001
B  204088111 3.0       .306028364 2.25 817 3640      12 26   180     0000
A    360001110371587330.30                    200133408-08     12
B  200133110 2.8       .307228169 3.13 979 4200      18 37    20     0000
   12.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     3.3 3. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  17.8  18.5
A    360001110671637430.26                    200166408-08     13
B  200166107 2.8       .307230269 4.06 813 4140      23 94    20     0000
   13.  1.6 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     4.3 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  20.4  21.2
A    360001111971587330.28                    200233408-08    962
B  200233108 2.95      .303830007 3.75 689 2500      58 31     0        0
  962.  1.2 6. 0. 0. 0. 0. 6. 0. 0. 0. 0. 0.     1.4 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  17.5  17.7
A    360001112371597530.37                    200241408-08    963
B  200241109 3.00      .303630040 2.94 123  541      14 25     0        0
  963.  2.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.8 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  24.1  20.0
A    360001120371607530.07                    200296408-08    962
B  200296105 2.85      .304230145 2.94 516 2200      34 38     0        0
  962.  3.0 1. 8. 1. 2. 0. 0. 0. 0. 0. 0. 0.     2.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  15.4  17.8
A    360001120771506830.32                    200313408-08    963
B  200313108 2.85      .304229868 3.50 254  499      32 21     0        0
  963.  4.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  19.8  18.9
A    360001112871627530.20                    200256408-08   1752
B  200256108 2.85      .304229992 2.06 673 2140      42 41    40        0
 1752.  4.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     3.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  19.8  19.5
A    360001120171567030.32                    200273408-08   1753
B  200273102 2.96      .303729098 3.13 587 1900      26 32     0        0
 1753.  5.0 3. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  15.4  17.8
A    360001102971557630.35                    200097408-08   2462
B  200097110 2.8       .307229973 2.0 1000 6180      14 26   300     0000
 2462.  2.0 1. 3. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  18.0  18.0
A    360001110171547330.36                    200116408-08   2463
B  200116114 2.8       .307228250 4.001000 5500       6 26 00000     0000
 2463.  0.5 1. 3. 0. 0. 0. 0. 0. 0. 0. 0. 0.     5.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  20.0  21.5
A    360002092771607930.11                      3542408-08    001
B     3542108 2.8           29663 3.50 439 2783      86 10    31     0000
A    360002101171607730.07                      3836408-08    012
B     3836108 2.8      .297528479 3.38 428 2362      96 10    28     0000
   12.  0.5 1. 0. 0. 0. 0. 3. 0. 0. 0. 0. 0.     0.1 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.0  15.5
A    360002101271728830.03                    203860408-08    013
B  203860111 2.8       .297529624 3.38 294 1581      85 13    31     0000
   13.  0.1 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.6  23.0
A    360002121071587030.34                    200327408-08    332
B  200327104 2.85      .304230050 4.06 649 5260      20 33     0        0
  332.  5.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     1.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.8  23.8
A    360002121471557329.98                    200340408-08    333
B  200340108 2.85      .304230211 3.00 321 1984      48 25     0        0
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Table D-2. EMISSION AND DRIVEABILITY TEST DATA (Continued)

```
  333.  2.0 1. 0. 0. 0. 0. 0. 2. 0. 0. 0. 0. 0.    3.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.5  22.7
A     360002110671617630.26                       200168408-08     962
B  200168108 2.80      .307229530 4.0  552 3580      55 27     0         0
  962.  2.0 1. 3. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.    2.0 1. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.8  21.5
A     360002112371576930.38                       200240408-08     963
B  200240109 2.91      .303930131 3.38  70  174      20 29     0         0
  963.  9.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.2  21.5
A     360002120271507030.41                       200283408-08     962
B  200283101 2.96      .303729928 3.75 631 4340      28 25     0         0
  962.  0.0 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    3.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.0  25.5
A     360002120771567230.12                       200308408-08     963
B  200308107 2.94      .303830153 4.19 183 1618    1638 33     0         0
  963.  0.0 0. 0. 0. 0. 0.19. 0. 0. 0. 0. 0. 0.    1.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 3. 0. 0. 0.  12.0  25.8
A     360002101871537330.21                       204013408-08    2462
B  204013108 3.0       .300728188 3.25 585 3600     109 20   220      0000
 2462.  0.5 1. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.2  20.2
A     360002102071537130.24                       204055408-08    2463
B  204055110 2.8       .301729070 4.06 400 2190      65  7    34      0000
 2463.  0.5 1. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.7  21.7
A     3600030924716880 30.09                        3527408-08     001
B     3527110 2.72     .297928709 3.37 380 1012     197  8    25      0000
A     360003103071506930.41                       200106408-08      12
B  200106110 2.8       .307228181 4.5  394 2575     134 14     2      0000
   12.  2.0 1. 1. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.8  23.5
A     360003110271597730.35                       200131408-08      13
B  200131111 2.8       .307228477 2.5  435 1008     102 27 00000      0000
   13.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  14.3  25.0
A     360003102371596830.09                       204085408-08     692
B  204085109 2.8       .307228187 3.56 359 2190     104 15    31      0000
  692.  0.5 1. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.3  26.2
A     360003102671536830.32                       104105408-08     693
B  104105113 2.8       .307228748 3.9  221 1507      76 16    31      0000
  693.  0.5 1. 0. 0. 3. 0. 0. 2. 0. 0. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.4  22.4
A     360003111971547630.32                       200231408-08     962
B  200231108 2.94      .303829910 3.25 417 3020      75 24    20        .2
  962.  5.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.2  23.7
A     360003112371637230.32                       200243408-08     963
B  200243107 2.95      .303629952 3.50 279 2631      19 20     0         0
  963.  5.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.5  24.3
A     360003120371597230.14                       200293408-08     962
B  200293108 2.85      .304230088 3.94 453 2020      64 35     0         0
  962.  1.2 2. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0.    2.5 1. 0. 0. 4. 0. 0. 9. 0. 0. 0. 0. 0. 0.  13.0   0.0
A     360003120771587130.12                       200307408-08     963
B  200307107 2.85      .304229863 4.06 161  991      45 18     0         0
  963.  4.0 1. 0. 1. 2. 0. 0. 0. 0. 0. 0. 0. 0.    1.5 1. 0. 0. 0. 0. 0. 0. 2. 0. 0. 0. 0. 0.  14.1  24.4
A     360003112871627430.14                       200261408-08    1752
B  200261106 2.85      .304229284 4.00 672 4000      58 33     0         0
 1752.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.5  25.5
A     360003120171577830.28                       200276408-08    1753
B  200276109 2.96      .303729633 4.69 445 3140      37 20    20         0
 1753.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.5  22.3
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Table D-2. EMISSION AND DRIVEABILITY TEST DATA (Continued)

```
A     360003101571667829.98                                  203957408-08     2462
B  203957107 2.2        .297528849 4.62 391 2929          111 12      25     00.4
 2462.  0.5 1. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0.        0.2 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  14.2  24.0
A     360003101971536430.42                                  204029408-08     2463
B  204029107 2.8        .301729187 3.62 427 1942           57  5      31     0000
 2463.  0.5 1. 0. 0. 0. 0. 8. 2. 0. 0. 0. 0. 0.        0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.2  25.5
A     360004100871728730.12                                     3817408-08      001
B     3817110 2.8       .297528196 2.13 442 1408           29  7      19     00.2
A     360004103071566830.43                                  200105408-08       12
B  200105110 2.8        .307228318 3.0  456 1891           71 20 C0000     0000
    12.  5.5 2. 0. 0. 2. 0. 0. 0. 0. 0. 0. 0. 0.        2.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.5  22.0
A     360004110271527630.36                                  200130408-08       13
B  200130107 2.8        .307229294 3.5  425  977           65 25 00000     0000
    13.  3.0 2. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0.        3.0 1. 0. 0. 0. 0. 0. 0. 5. 0. 0. 0. 0. 0.  12.5  23.0
A     360004110671658130.19                                  200170408-08      102
B  200170107 2.8        .307230008 3.5  565 1932           64 29      2      0000
   102.  2.0 1. 0. 1. 1. 0. 0. 0. 0. 0. 0. 0. 0.        2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.2   0.0
A     360004110971597230.34                                  200178408-08      103
B  200178109 2.8        .307229922 3.38 314 1179           30 24 C0000     0000
   103.  0.8 1. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0.        3.1 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.4  23.0
A     360004121071577230.34                                  200332408-08      332
B  200332104 2.85       .304230037 3.25 500 2316           47 37      0         0
   332.  3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        2.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.3  24.5
A     360004121471577330.00                                  200339408-08      333
B  200339107 2.85       .304230248 3.63 432 1670           31 25      0         0
   333.  2.3 3. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0.  11.7  22.7
A     360004101371657430.14                                     3888408-08      422
B     3888107 2.8       .297528107 3.38 412 2144           63 15      18        00
   422.  0.1 1. 0. 0. 1. 0. 0. 1. 0. 0. 0. 0. 0.        0.1 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.7  23.7
A     360004101471627230.10                                     3916408-08      423
B     3916110 3.0       .296428236 3.38 441 1095           69  8      15        00
   423.  0.3 1. 3. 0. 7. 0. 0. 0. 0. 0. 0. 0. 0.        0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.2  24.2
A     360004102371627030.08                                  204086408-08      692
B  204086110 2.8        .307229363 3.5  333 1906           63 15      29     0000
   692.  1.5 1. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0.        3.0 2. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.  11.9  22.3
A     360004102671546430.31                                  104104408-08      693
B  104104109 2.8        .307230265 4.06 235 1156           71 13      31     0000
   693.  0.5 1. 0. 0. 2. 0. 0. 1. 0. 0. 0. 0. 0.        5.3 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.6  24.6
A     360004111371597330.33                                  200204408-08      962
B  200204109 2.8        .307230097 3.25 543 2010           56 31      1      0000
   962.  3.0 2. 0. 2. 0. 0. 0. 0. 0. 0. 0. 0. 0.        5.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.5  23.0
A     360004111671547330.26                                  200219408-08      963
B  200219108 2.96       .303730479 3.94  86   17           38 17 C0000     0000
   963.  2.0 5. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0.        3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.0  26.8
A     360004111971547630.32                                  200231408-08      962
B  200232106 2.94       .303830097 3.19 500 1566           54 30      2         0
   962.  1.0 1. 1. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0.        1.2 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.6  22.5
A     360004112371597430.35                                  200242408-08      963
B  200242109 2.99       .303630254 3.38 143  366           21 26      0         0
   963.  6.6 4. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0.        2.0 1. 0. 0. 0. 0. 0. 0.23. 0. 0. 0  0. 0.  12.7  26.4
A     360004112871627530.12                                  200259408-08     1752
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Table D-2. EMISSION AND DRIVEABILITY TEST DATA (Continued)

```
B  200259107 2.85       .304230080 3.25 429 2225        37 33     0          0
 1752.  7.0 3. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.0  23.2
A     3600041001715879 30.28                        200277408-08    1753
B  200277108 2.96       .303730004 3.38 400 2052        35 21     0          0
 1753.  5.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.2  20.7
A     3600041018715373 30.21                        204014408-08    2462
B  204014107 2.8        .301729263 3.62 546 1806       101 18     15        00.6
 2462.  0.4 2. 0. 0. 2. 0. 0. 0. 0. 0. 0. 0. 0.        0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.6  20.8
A     3600041020715474 30.23                        204056408-08    2463
B  204056109 2.8        .301729265 3.88 525 1409        63 10     34        0000
 2463.  0.5 1. 0. 0. 2. 0. 1. 0. 0. 0. 0. 0. 0.        2.4 1. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.  12.5  23.0
A     3600050929715968 30.01                          3576408-08     001
B     3576101 2.7       .298027914 4.25 352 2762       110  4     19        0000
A     3600051106716583 30.19                        200171408-08    0012
B  200171107 2.8        .307229637 4.19 516 3240        44 22     20        0000
  12.  0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        8.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.5  28.9
A     3600051102715471 30.36                        200129408-08     13
B  200129107 2.8        .307229750 3.5  416 1873        49 29      5        0000
  13.  2.0 1. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.        3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.4  22.0
A     3600051013716676 30.16                          3889408-08     422
B     3889105 2.8       .297529458 4.44 882 4700        69 15    128         1.0
 422.  0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        0.3 1. 0. 0. 0. 0. 0. 0. 5. 0. 0. 0. 0. 0.  10.0  23.7
A     3600051014716373 30.11                          3915408-08     423
B     3915104 3.0       .296428021 3.88 429 2900        69  5     29        0000
 423.  0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        4.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.2  26.7
A     3600051113716175 30.30                        200207408-08     692
B  200207108 2.8        .307229918 4.25 496 2580        67 28     20        0000
 692.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.1  26.5
A     3600051117716072 30.37                        200229408-08     693
B  200229108 2.95       .303830043 3.5  352 2068        36 24 C0000        0000
 693.  3.0 3. 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.0  31.8
A     3600051120715373 30.35                        200235408-08     962
B  200235108 2.95       .303829680 3.81 433 2220        42 30      0          0
 962.  4.5 2. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0.        3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   8.9  29.4
A     3600051123715872 30.39                        200239408-08     963
B  200239106 2.95       .303830125 3.94 259 1653        13 25      2          0
 963.  4.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.8  24.1
A     3600051203716076 30.10                        200295408-08     962
B  200295104 2.85       .304229941 4.06 526 3060        51 31      0          0
 962.  1.4 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        0.8 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   8.3  19.2
A     3600051206715875 30.01                        200305408-08     963
B  200305104 2.85       .304229749 4.44 334 2261        38 26      2          0
 9633.  0.020. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        6.0 1. 0. 0. 0. 0. 0. 0.16. 0. 0. 0. 0. 0.   8.7  23.8
A     3600051128716377 30.16                        200257408-08    1752
B  200257106 2.85       .304230286 4.00 528 3260        41 39     20          0
 1752.  1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        3.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   8.8  22.0
A     3600051201715673 30.32                        200274408-08    1753
B  200274106 2.96       .303729754 4.75 629 3620        30 27      0          0
 1753.  1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.2  18.5
A     3600051106716583 30.19                        200171408-08    2952
B  200171107 2.8        .307229637 4.19 516 3240        44 22     20        0000
```

Table D-2. EMISSION AND DRIVEABILITY TEST DATA (Continued)

```
 2952.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    6.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.2  23.0
A    360005110971638230.28                      200181408-08    2953
B 200181109 2.8      .307229615 4.69 712 2580      34 35 00000     0000
 2953.  9.612. 0. 3. 3. 0. 2. 0. 0. 2. 0. 0. 0.    2.0 2. 0. 0. 0. 0. 0.10. 0. 0. 0. 0. 0. 0.  10.3  27.0
A    360006092871637929.97                        3578408-08     001
B    3578111 2.8      .297527854 3.81 362 1834     127  7     29     0000
A    360006101171668130.08                        3837408-08     012
B    3837112 2.8      .297528082 3.69 737 2373      59 14     31     0000
  12.  0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    0.1 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  15.9  20.5
A    360006101571667929.99                        3956408-08     013
B    3956109 2.8      .297529540 3.12 369 1441      48  8     20     0000
  13.  0.5 2. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0. 0.    0.1 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  17.1  26.2
A    360006110671617430.25                      200167408-08     102
B 200167108 2.8      .307229748 3.69 403 2631      42 30      5     0000
 102.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  15.2  24.0
A    360006110971627730.34                      200179408-08     103
B 200179110 2.8      .307228926 3.81 303 2209      21 25      2     0000
 103.  2.0 3. 2. 0. 0. 0. 4. 3. 0. 0. 0. 0. 0.    2.8 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  20.0  22.5
A    360006111371617630.38                      200205408-08     962
B 200205108 2.8      .307229867 3.44 462 2260      35 26     20     0000
 962.  3.0 8. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  17.5  27.2
A    360006111671597330.24                      200220408-08     963
B 200220108 2.96     .303729809 4.13 158 1545      24 15      5     0000
 963.  4.010. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    1.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  17.4  24.3
A    360006111971527130.30                      200232408-08     962
B 200232110 2.94     .303830062 3.44 359 2142      39 24      0       .2
 962.  1.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    3.8 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  15.6  24.0
A    360006112371577030.40                      200238408-08     963
B 200238108 2.95     .303830381 4.31 194 2021      30 25      2        0
 963.  4.0 2. 0. 3. 3. 0. 0. 0. 0.12. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  19.1  26.8
A    360006102671587130.33                      104110408-08    2452
B 104110113 2.8      .307230335 2.75 282 2062      47 18     24     0000
2452.  0.5 1. 0. 1. 0. 0. 2. 0. 0. 0. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  17.3  23.1
A    360006101971516830.44                      204030408-08    2453
B 204030112 2.8      .301728238 3.06 400 2844      44 10     31     0000
2453.  0.5 1. 0. 0. 0. 0. 6. 0. 0.10. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0.12. 0. 0. 0. 0.  23.9  21.9
A    360006102671587130.33                      104110408-08    2882
B 104110113 2.8      .307230335 2.75 282 2062      47 18     24     0000
2882.  2.0 1. 0. 0. 1. 0. 3. 0. 0. 0. 0. 0. 0.    1.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  18.0  26.0
A    360006102971556930.32                      200096408-08    2883
B 200096117 2.8      .307229261 3.13 282 1405      70 12     18        1
2883.  0.1 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  14.9  30.0
A    706008110671627229.42                         54407-01       12
B       54111 2.73    .298426880 4.00 450 1985      99 78     67        1
  12.  1.3 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.1  20.2
A    706008110971637429.60                         66407-01       13
B       66115 2.73    .298428201 3.38 294  226      73 85     31        3
  13.  1.0 4. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  14.1  21.8
A    706008111371597229.33                         94407-01       12
B       94113 2.74    .298328478 3.68 284 1906      85 10     10        1
  12.  0.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.9  21.5
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Table D-2. EMISSION AND DRIVEABILITY TEST DATA (Continued)

```
A     706008111671607229.66                          110407-01      13
B        110113 2.80      .297727956 2.50 289  430      99 21       7         1
   13.  4.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.5  20.7
A     706008112771627228.99                          201407-01     962
B       201111 2.94       .296428400 2.25 276 2000      55 33      14         1
  962.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.7  17.9
A     706008113071587129.30                          219407-01     963
B       219110 2.79       .297728277 3.43 104  645      28 24      10         1
  963.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.5   0.0
A     706008120671607129.49                          268407-01    1752
B       268114 2.79       .297728531 3.31 295 1906      84 52      41         2
 1752.  8.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.7  20.7
A     706008120771597329.30                          283407-01    1753
B       283111 2.82       .297428521 3.50 286  442      37 83       2         0
 1753.  2.0 1. 0. 0. 3. 0. 0. 0. 0. 0. 0. 0. 0.     7.0 1. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  17.7  21.6
A     706008112071607128.62                          142407-01    2462
B       142110 2.80       .297728042 3.62 296 1358      73 42      49         1
 2462.  4.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     1.3 3. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.4  17.7
A     706008112471607229.68                          169407-01    2463
B       169109 2.80       .297728510 3.18 284 1298      29 18      12         0
 2463.  2.0 1. 0. 0. 0. 0. 0. 2. 0. 0. 0. 0. 0.     2.0 1. 2. 0. 0. 0. 0. 0. 0. 0. 4. 0. 0. 0.  13.4   0.0
A     706009110671617130.22                           52407-01      12
B        52113 2.73       .298426822 3.56 398 2426     127 63      82         3
   12.  1.0 1. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.     1.2 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.7  21.4
A     706009110971657829.61                           65407-01      13
B        65114 2.73       .298428045 2.38 324  506     104 83      31         3
   13.  1.0 1. 0. 0. 0. 0. 4.12. 0. 0. 0. 0. 0.     1.2 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.7  26.2
A     706009111371577029.44                           91407-01      12
B        91112 2.73       .298428558 3.43 340 1302     123 37      10         1
   12.  0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     0.7 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.5  23.5
A     706009111671586929.66                          109407-01      13
B       109113 2.80       .297727446 2.87 324  887      95 31      10         2
   13.  0.5 1. 1. 3. 0. 0. 0. 0. 0. 0. 0. 0. 0.     0.7 1. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0.  13.1  22.6
A     706009112771587028.99                          199407-01     962
B       199109 2.94       .296428134 3.56 270 1615     101 34      45         3
  962.  4.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.5  21.3
A     706009113071587229.32                          221407-01     963
B       221111 2.79       .297727434 3.25  53  282      43 18      16         1
  963.  4.0 1. 0. 0. 1. 0. 0.17. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 1. 0. 3. 0. 0. 0. 0.  14.3   0.0
A     706009120671597029.52                          264407-01    1752
B       264112 2.79       .297728534 3.68 324 1877      81 59      55         0
 1752.  3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.9  21.8
A     706009120771647529.25                          285407-01    1753
B       285112 2.82       .297428690 3.50 247  393      44 51       2         0
 1753.  1.5 1. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.6  23.2
A     706009103071687830.30                            9407-01    2462
B         9110 2.65       .299026821 3.63 460 3300      84 57      64         2
 2462.  1.0 1. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0.     0.8 1. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0. 0.  13.4  22.9
A     706009110271617229.08                           26407-01    2463
B        26113 2.65       .299027131 3.31 405 1500      51 21     100         1
 2463.  6.0 1. 0. 0. 0. 0.52.10. 0. 0. 0. 0. 0.     0.5 1. 0. 0. 0. 0. 0.15. 0. 0. 2. 0. 0. 0.  13.8  24.3
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Table D-2. EMISSION AND DRIVEABILITY TEST DATA (Continued)

```
A      706009112071627328.60                         148407-01    2462
B        148110 2.80      .297727360 3.43 264 1540      87 25     23        1
 2462.  6.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.4  20.0
A      706009112471586929.66                         170407-01    2463
B        170110 2.80      .297728515 3.43 250  569      35 19     21        0
 2463.  2.0 2. 1. 1. 0. 0. 0.10. 0. 0. 0. 0. 0.     1.5 1. 0. 0. 0. 0. 0. 2. 0. 3. 5. 0. 0. 0.  13.5   0.0
A          10102071698030.49                          1407-01     001
B          1110 2.65      .299026632 5.38 68813500      13 10      0        0
A      706010110671647429.42                          55407-01     12
B         55112 2.73      .298426980 3.75 594 2631     147 62     62        2
   12.  1.1 2. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0. 0.     3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.2  24.3
A      706010110971607429.51                          63407-01     13
B         63113 2.73      .298428490 3.01 732  167     153 83      0        4
   13.  0.8 2. 0. 0. 0. 0. 5. 0. 0. 0. 0. 0. 0.     3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.4  24.2
A      706010111371556829.37                          90407-01     12
B         90112 2.74      .298328442 3.25 415 1382     117 21     10        1
   12.  0.0 0. 0. 0. 0. 0. 0. 5. 0. 0. 0. 0. 0.     2.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.4  24.3
A      706010111671617329.65                         112407-01     13
B        112113 2.80      .297727512 3.25 435  410     134 41     30        2
   13.  0.0 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.     2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.5  23.0
A      706010112771617229.99                         203407-01     962
B        203109 2.94      .296428145 4.62 334 1429     110 30     10        2
  962.  2.0 1. 1. 0. 0. 0. 1. 6. 0. 0. 0. 0. 0.     5.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.7  20.2
A      706010113071647429.22                         217407-01     963
B        217109 2.79      .297727551 3.50 140  333      44 48      2        3
  963.  2.0 1. 0. 0. 0. 0. 0. 4. 0. 0. 0. 0. 0.     3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.6  19.3
A      706010120671597029.49                         267407-01    1752
B        267113 2.79      .297728522 3.25 369 1353      84 61     23        2
 1752.  0.5 1. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.     2.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.2  21.1
A      706010120771667829.21                         288407-01    1753
B        288114 2.82      .297428530 4.00 314  531      33 61      6        0
 1753.  4.0 1. 0. 0. 0. 0. 8. 0. 0. 0. 0. 0. 0.     1.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.0  24.7
A      706010112071657628.62                         146407-01    2462
B        146110 2.80      .297728445 1.87 350 1556      69 31     25        0
 2462.  4.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     4.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.9  20.3
A      706010112471586829.66                         167407-01    2463
B        167105 2.80      .297728484 3.31 266  801      32 13      6        0
 2463.  1.5 1. 0. 0. 0. 0. 2. 2. 0. 0. 0. 0. 0.     4.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.0   0.0
A      706011102071677830.47                      000002407-01     001
B          2112 2.65      .299026690 3.75 86210400      51 10      0        0
A      706011110671617129.41                          53407-01     12
B         53113 2.73      .298426868 3.56 570 3500      80 57     62        3
   12.  1.8 2. 5. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     1.0 2. 0. 0. 0. 0. 0. 0. 5. 0. 0. 0. 0. 0.   9.9  20.4
A      706011110971637429.61                          64407-01     13
B         64114 2.73      .298428505 3.19 450  868      95 83     31        4
   13.  1.0 1. 1. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0.     1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.6  22.5
A      706011111371597429.37                          93407-01     12
B         93112 2.82      .297627831 4.31 629 3700      73 43     14        1
   12.  0.5 1. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.     0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  10.7  23.7
A      706011111671657629.64                         108407-01     13
B        108113 2.80      .297727947 3.37 319 1350     104 36     10        2
```

Table D-2. EMISSION AND DRIVEABILITY TEST DATA (Continued)

```
   13.  0.1 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.3  23.8
A     706011112771607129.99                       000202407-01     962
B      202111 2.96      .296227368 3.31 279 2186      63  2     21        1
  962.  5.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.7  20.8
A     706011113071607029.23                       000218407-01     963
B      218110 2.79      .297727744 3.00  53   35      26 33     25        1
  963.  2.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.8  20.7
A     706011120671586929.49                       000266407-01    1752
B      266114 2.79      .297728484 3.81 267 1687      51 41     23        0
 1752.  0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    3.5 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.7  21.0
A     706011120771647529.23                       000286407-01    1753
B      286111 2.82      .297428443 3.56 234  428      46 62      4        0
 1753.  4.0 1. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0.    3.5 2. 0. 0. 0. 0. 0. 0. 3. 2. 0. 0. 0. 0.  10.3  22.2
A     706011103071698030.31                          11407-01    2462
B       11109 2.65      .299026477 3.75 525 4200      79 10      0        0
 2462.  0.8 1. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0.    3.0 1. 0. 0. 0. 0. 0. 0. 6. 0. 0. 0. 0. 0.  10.1  25.4
A     706011110271627229.72                          24407-01    2463
B       24112 2.65      .299027008 3.56 435 2900      49 10      0      1.4
 2463.  1.0 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.   9.8  23.1
A     706011112071647628.68                         145407-01    2462
B      145110 2.80      .297728370 4.00 388 3050      60 26     45        0
 2462.  6.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  11.7  19.1
A     706011112471617129.70                         166407-01    2463
B      166110 2.88      .297028508 2.93 204  786      30 16      0        0
 2463.  1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.8   0.0
A     706012102071657430.46                           4407-01     001
B        4113 2.65      .299026488 3.44 599 7800      47 13     40        0
A     706012110771567629.40                          51407-01      12
B       51112 2.73      .298426852 3.00 634 2595      86 72     78        4
   12.  0.5 1. 0. 0. 0. 0. 0. 9. 0. 0. 0. 0. 0.    0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.3  24.3
A     706012110971637529.54                          67407-01      13
B       67114 2.73      .298426878 2.94 375 1286      73 72     41        3
   13.  1.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.2  28.0
A     706012111371567229.44                          92407-01      12
B       92112 2.74      .298328457 2.68 455 1833      64 31     10        1
   12.  1.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.6  24.2
A     706012111771657629.66                         111407-01      13
B      111113 2.80      .297727195 3.56 465  912      78 31     10        2
   13.  2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.5  26.4
A     706012112771697728.94                         200407-01     962
B      200110 2.94      .296428451 3.18 270 1228      60 30     10        0
  962.  5.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.0  24.1
A     706012113071577329.31                         220407-01     963
B      220112 2.81      .297628150 3.31  55   58      38 22      8        0
  963.  2.0 1. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  14.3  24.1
A     706012120671607129.50                         269407-01    1752
B      269114 2.79      .297728537 3.50 345 1283      61 58     27        1
 1752.  2.0 1. 0. 0. 0. 0. 1. 3. 0. 0. 0. 0. 0.    1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.3  25.0
A     706012120771657729.27                         287407-01    1753
B      287113 2.82      .297428531 4.37 264  430      38 72     12        0
 1753.  2.0 1. 0. 0. 0. 0. 4. 5. 0. 0. 0. 0. 0.    2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.6  28.1
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Table D-2. EMISSION AND DRIVEABILITY TEST DATA (Concluded)

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A     706012103071667730.29                          8407-01     2462
B        8110 2.65      .299025751 3.13 634 2563       87 64     62       16
 2462.  1.0 1. 0. 0. 0. 0. 0.11. 0. 0. 0. 0. 0.      1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  15.4  24.7
A     706012110371697829.94                         30407-01     2463
B       30111 2.65      .299026863 3.25 535 1700       38 36      0        0
 2463.  1.0 1. 0. 0. 0. 0. 3. 5. 0. 0. 0. 0. 0.      2.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  14.7  28.8
A     706012112071607128.70                        142407-01     2462
B      142110 2.80      .297727393 2.81 392 ~~2600~~1950  58 22     12       0
 2462.  6.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.      2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  13.5  19.9
A     706012112471597029.67                        168407-01     2463
B      168113 2.80      .297728506 3.19 233  852       32 27     12       0
 2463.  6.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.      2.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  14.6   0.0
A     706016112071637428.71                        142407-01     1752
B      142110 2.79      .297727485 2.87 383 1632      109 21     10       1
 1752.  1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.      3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.3  22.9
A     706016120771657729.27                        284407-01     1753
B      284113 2.82      .297428511 3.87 280  412       57 73      2       0
 1753.  1.5 1. 0. 0. 0. 0. 0. 3. 0. 0. 0. 0. 0.      3.0 1. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0. 0.  15.5  23.3
A     360017100771688830.01                       3795408-08      001
B     3795111 2.87      .297128395 5.31 506 7940       10  9    280      0000
A     360017101871527330.28                     204015408-08     2462
B  204015105 2.8        .301728142 4.94 714 5340       75 28    240      00.4
 2462.  0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.      0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.1  19.8
A     360017102171527130.31                     204060408-08     2463
B  204060108 3.01       .305928692 4.38 682 4800       30 17    320      0000
 2463.  0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.      0.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  12.7  25.0
A     360019120371617530.01                     200298408-08       12
B  200298104 2.85       .304230589 2.31 669 2190       32 41      0        0
   12.  1.7 3. 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.      2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  27.6  18.9
A     360019120771516930.32                     200314408-08       13
B  200314101 2.85       .304230012 3.19 364  946       32 27      0        0
   13.  1.7 3. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.      2.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  31.0  15.1
A     706020102071657230.43                          5407-01      001
B        5111 2.65      .299026230 1.80 235 2600       46  9     20        0
A     706020120671597029.50                        265407-01       12
B      265113 2.79      .297728482 2.18 465 1244       48 62     21        1
   12.  0.0 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.      1.5 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  32.4   0.0
A     706020120771627229.22                        289407-01       13
B      289112 2.82      .297428553 3.06 164  179       42 47      0        0
   13.  0.0 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.      3.0 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  34.2   0.0
0                    END OF DATA
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Table D-3. RETROFIT DEVICE EVALUATION INPUT DATA

KEY PUNCH FORM - GENERAL PURPOSE
FORM 2168 (R2-68) REPLACES 474

JOB TITLE: RETROFIT DEVICE DATA
ENGINEER: E. L. Klebba
PAGE: 1 OF 3
ANALYST: F. S. Stark
DATE:
OPNA SERIAL NO.
PRE.
OPN JOB NO.
DASH
FOR ORGN. NO.

DEVICE NO.	STDS	SAF	MMBTF (MILES)	MTTR (HRS)	MMBM (MILES)	MTTM (HRS)	MMBPF (MILES)		REPAIR PART COST ($)	MAINT PART COST ($)	RETAIL COST ($)	INST TIME (HRS)	ADPTR COST ($)			COVERAGE (% POP.)
1.	.5	1	75000.	0.75	12000.	0.30	75000.		14.50	2.50	48.00	1.25	0.00			90.
10.	.5	1	50000.	0.55	12000.	0.50	50000.		11.00	1.25	55.00	1.25	0.00			90.
22.	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
23.	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
24.	(1)	(1)	100000.	0.75	25000.	0.25	100000.		24.40	0.00	24.40	0.75	0.00			(1)
31.	(1)	1	50000.	3.00	12000.	0.25	50000.		50.00	3.00	80.00	5.00	0.00			(1)
33.	.5	0	75000.	1.00	00000.	0.00	75000.		8.65	0.00	8.65	1.00	0.00			90.
36.	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
42.	.5	1	75000.	1.00	12000.	0.20	75000.		10.00	0.00	10.00	1.00	0.00			90.
52	(1)	(1)	300000.	12.00	25000.	0.25	300000.		457.95	2.00	457.95	12.00	0.00			(1)
56	2	0	75000.	0.72	12000.	0.30	75000.		12.50	2.00	35.00	1.50	0.00			90.
57	(1)	0	50000.	1.00	12000.	0.40	50000.		10.00	2.50	41.00	1.75	0.00			90.
59	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			90.
62	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
69	5	1	75000.	0.65	12000.	0.30	75000.		23.00	0.00	50.00	1.00	0.00			90.
93	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
95	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			100.
96	.5	1	50000.	1.67	8333.	0.27	50000.		35.00	16.25(4)	125.00	4.00	0.00			90.
100	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
160	6	1	75000.	0.75	12000.	0.25	75000.		15.00	3.00	53.50	1.25	0.00			90.
164	(1)		(1)	(1)	(1)	(1)	(1)		(1)	(1)	90.00	1.00	0.00			90.
165	5	0	50000.	0.75	12000.	0.50	50000.		19.50	2.50	175.00	5.00	0.00			75.
170	(1)	(1)	100000.	1.75	12000.	0.25	100000.		17.00	0.00	17.00	1.75	0.00			90.
172	5	1	75000.	1.50	00000.	0.00	75000.		60.00	0.00	60.00	1.50	0.00			90.
175	5	1	75000.	1.00	00000.	0.00	75000.		32.00	0.00	32.00	1.00	0.00			90.

Table D-3. RETROFIT DEVICE EVALUATION INPUT DATA (CONT)

KEY PUNCH FORM - GENERAL PURPOSE
FORM 2168 (R2-68) REPLACES 474

JOB TITLE: RETROFIT DEVICE DATA
CPWA SERIAL NO.:
PRE:
CFD JOB NO.:
DASH:
FOR ORGN. NO.:
ENGINEER: E. L. Klebba
ANALYST: F. S. Stark
PAGE: 2 of 3
DATE:

DEVICE NO.	STDS	SAF	MMBTF (MILES)	MTTR (HRS)	MMBM (MILES)	MTTM (HRS)	MMBPF (MILES)		REPAIR PART COST ($)	MAINT PART COST ($)	RETAIL COST ($)	INST TIME (HRS)	ADPTR COST ($)			COVERAGE (% POP.)
182	(1)	(1)	(2)	(2)	(2)	(2)	(2)		(2)	(2)	1.10	0.00	0.00			(1)
244	5	1	75000.	8.00	12000.	0.25	75000.		275.00	1.25	275.00	8.00	0.00			80.
245	7	1	75000.	2.25	25000.	0.50	75000.		50.00	0.00	50.00	2.25	0.00			90.
246	5	1	75000.	0.87	6000.	0.50	75000.		16.00	1.25	61.00	2.25	0.00			90.
259	5	1	75000.	0.75	25000.	0.50	75000.		50.00	0.00	50.00	0.75	0.00			90.
268	(1)	1	150000.	0.75	00000.	0.00	150000.		60.00	0.00	60.00	0.75	0.00			90.
279	4	0	50000.	0.50	00000.	0.00	50000.		10.00	0.00	10.00	0.50	0.00			100.
282	(1)	1	50000.	1.20	12000.	0.70	50000.		24.50	0.00	80.00	3.00	0.00			90.
288	2	1	75000.	1.25	00000.	0.00	75000.		25.00	0.00	25.00	1.25	0.00			90.
292	3	1	50000.	0.75	12000.	0.25	50000.		40.00	2.50	60.00	1.00	0.00			90.
294	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
295	4	1	75000.	0.75	12000.	0.50	75000.		70.00	0.00	70.00	0.75	0.00			90.
296	2	1	75000.	0.25	00000.	0.00	75000.		20.00	0.00	20.00	0.25	0.00			90.
308	2	1	50000.	0.50	12000.	0.80	50000.		18.00	3.00	35.00	1.25	20.00			90.
315	(1)	0	50000.	0.75	25000.	0.75	50000.		18.33	0.00	40.00	1.50	10.00			90.
317	3	0	75000.	0.75	12000.	0.20	75000.		13.95	0.00	13.95	0.75	0.00			90.
322	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
325	5	1	50000.	0.60	2500.	0.50	50000.		13.50	2.30	40.00	1.25	0.00			90.
384	(1)	(1)	75000.	(1)	25000.	0.08	75000.		(1)	0.00	(1)	(1)	(1)			90.
401	2	1	50000.	0.60	2500.	0.50	50000.		13.25	2.50	30.00	1.00	3.00			90.
408	(1)	0	50000.	0.81	12000.	0.50	50000.		11.50	2.00	20.00	1.25	0.00			90.
418	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
425	2	0	50000.	0.75	12000.	0.45	50000.		61.25	1.50	125.00	1.50	15.00			90.
427	5	1	50000.	0.75	5000.	0.46	50000.		15.00	3.00(4)	52.00	1.25	0.00			90.
430	5	1	75000.	0.75	25000.	0.08	75000.		10.00	0.00	10.00	0.75	0.00			90.

Table D-3. RETROFIT DEVICE EVALUATION INPUT DATA (CONCL)

KEY PUNCH FORM - GENERAL PURPOSE
FORM 2168 (R2-68) REPLACES 474

JOB TITLE RETROFIT DEVICE DATA
ENGINEER E. L. Klebba
PAGE 3 OF 3
OPWA SERIAL NO.
PRE.
CPO JOB NO.
DASH
FOR ORGN. NO.
ANALYST F. S. Stark
DATE

DEVICE NO.	STDS	SAF	MMBTF (MILES)	MTTR (HRS)	MMBM (MILES)	MTTM (HRS)	MMBPF (MILES)		REPAIR PART COST ($)	MAINT PART COST ($)	RETAIL COST ($)	INST TIME (HRS)	ADPTR COST ($)			COVERAGE (% POP.)
433	5	1	50000.	0.60	2500.	0.50	50000.		13.50	2.30	40.00	1.25	0.00			90.
440	(1)	1	75000.	0.75	25000.	0.08	75000.		3.00	0.00	3.00	0.75	0.00			90.
457	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
458	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
459	(1)	(1)	300000.	12.00	25000.	0.25	300000.		457.95	2.00	457.95	12.00	0.00			(1)
460	(1)	(1)	300000.	(1)	(1)	(1)	100000.		(1)	(1)	451.14	12.00	(1)			(1)
461	(1)	(1)	75000.	18.00	25000.	0.25	75000.		575.00	2.00	575.00	18.00	(1)			(1)
462	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
463	(1)	(1)	(1)	(1)	12000.	0.25	(1)		(1)	1.25	(1)	(1)	(1)			(1)
464	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
465	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
466	(1)	(1)	300000.	(1)	25000.	0.25	100000.		(1)	2.00	457.95	12.00	(1)			(1)
467	(1)	(1)	(1)	(1)	12000.	0.25	(1)		(1)	1.00	(1)	(1)	(1)			(1)
468	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(1)	(1)	(1)			(1)
469	(1)	(1)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	400.00	(1)	(1)			(1)

NOTES:

(1) Insufficient data.

(2) Not applicable.

(3) 8-cylinder engine

(4) C_{MP} = \$5.42

(5) C_{MP} = \$1.00

APPENDIX E

COMPUTER PROGRAM RESULTS

This appendix presents the computer program results of the retrofit device performance analysis. The performance analysis input parameter data upon which these results are based are given in the previous Appendix D. Table E-1 presents a matrix of the 11 retrofit devices and 16 used cars tested at the Anaheim and Detroit facilities.

Table E-2 presents the Anaheim/Detroit retrofit device test results which compare the effects of specified devices upon emission levels, driveability, and cost. The table is arranged numerically by car identification number with an unranked sub-listing of retrofit devices tested on each car. Exhaust emission levels, with and without the device installed, are presented as baseline and retrofit, respectively. Specified performance analysis results include:

a. Baseline and retrofit emission levels of HC, CO, and NOx.

b. Fuel consumption, miles per gallon.

c. Emission Index, per unit of reduction.

d. Driveability Index, differential value.

e. Cost Index, dollars/100 miles.

f. Performance Index (Combines c., d., and e. above into overall device performance).

g. Cost Effectiveness Index = $\frac{\text{Emission Index}}{\text{Cost Index}}$

Negative values are interpreted as follows:

Emission Index	=	Overall increase of emissions above baseline level.
Driveability Index	=	Improved driveability.
Cost Index	=	Fuel consumption savings.
Performance Index	=	Emission reduction capability of a device(s) is less than vehicle driveability and cost Penalties.
Cost Effectiveness Index	=	With a positive Emission Index, a cost savings is achieved as well as an emission reduction. With a negative Emission Index, money would be paid to increase emissions; a clearly undesireable situation.

Table E-1. RETROFIT DEVICE TEST MATRIX

CAR ID NO(1)	RETROFIT DEVICE TESTED(2)										
	1	10	33	42	69	96	175	245	246	288	295
1	A					AA	A		A		
2	A		A			AA			A	(A)	
3	A				A	AA	A		A		
4	A	A	A	A	A	AA	A		A		
5	A			A	A	AA	A				A
6	A	A				AA	(3)	A		A	
8	DD					D	D		(3)D		
9	DD					D	D		DD		
10	DD					D	D		(3)D		
11	DD					D	D		DD		
12	DD					D	D		DD		
16							D				
17									A		
18									(3)		
19	A								(3)		
20	D								(3)		
TOTAL:	18	2	2	2	3	17	10	1	13	2	1

(1) Car identification number, Section 4 Table 4-1.
(2) A = One test Anaheim, California
D = One test Detroit (Taylor), Michigan
AA = Initial test plus 1 replicate installation.
DD = Initial test plus 1 replicate installation.
(3) Test not included in computer because of invalid data.

The emissions and fuel-miles-per-gallon data of Table E-2 following may differ slightly from the same data as presented in Appendices F and L. This difference is attributable to the use of a computer programmed method of calculation for the data of Table E-2; whereas, a desk calculator was used for the data of Appendices F and L.

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS

CAR NUMBER 1

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	12.477	110.194	0.579	20.567				
1.	BASELINE	15.110	135.372	0.844	14.784				
	RETROFIT	12.440	143.925	1.269	11.398	-0.130	0.316	0.840	-0.360
96.	BASELINE	11.089	85.064	2.856	12.340				
	RETROFIT	1.652	18.410	0.693	15.740	0.797	0.898	-0.210	0.643
96.	BASELINE	8.114	75.395	1.734	15.740				
	RETROFIT	3.934	17.009	1.447	13.221	0.485	0.549	0.916	-0.063
175.	BASELINE	10.667	71.564	2.203	(2)				
	RETROFIT	9.174	63.408	1.237	14.784	0.231	-0.447	(3)	(3)
246.	BASELINE	(1)	202.992	0.653	(2)				
	RETROFIT	(1)	177.776	0.263	11.569	(3)	0.461	(3)	(3)

(1) This value invalid due to offscale reading.

(2) Test data outlier not used.

(3) Index value not calculated, due to data deficiency.

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 2

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	6.992	90.557	4.099	13.221				
1.	BASELINE	6.533	73.647	4.448	13.691				
	RETROFIT	4.538	50.533	4.921	13.691	0.171	0.084	0.137	0.047
33.	BASELINE	10.545	181.798	1.020	11.398				
	RETROFIT	4.992	67.557	2.256	15.425	-0.019	0.182	-0.774	0.184
96.	BASELINE	8.846	121.793	2.807	11.569				
	RETROFIT	0.696	5.967	1.000	13.691	0.839	0.056	-0.053	0.486
96.	BASELINE	10.355	149.725	1.265	12.340				
	RETROFIT	2.531	55.115	0.768	11.044	0.593	-0.019	0.818	0.107
246.	BASELINE	8.814	106.463	4.596	14.238				
	RETROFIT	6.375	70.613	2.884	11.398	0.329	0.256	0.856	-0.093
288.	BASELINE	6.59	117.45	3.28	14.5	0.143	(1)	0.054	(1)
	RETROFIT	6.18	71.78	3.34	14.5				

(1) Index value not calculated, due to data deficiency.

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 3

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	5.870	31.442	10.654	13.731				
1.	BASELINE	6.122	83.697	5.743	10.283				
	RETROFIT	6.617	33.004	4.794	(1)	0.230	0.200	(2)	(2)
69.	BASELINE	5.489	69.553	5.125	12.999				
	RETROFIT	3.341	48.564	3.449	11.865	0.340	0.154	0.372	0.066
96.	BASELINE	6.614	101.933	3.385	14.238				
	RETROFIT	4.371	89.646	1.037	13.221	0.384	0.056	0.661	0.022
96.	BASELINE	7.062	68.907	3.247	11.745				
	RETROFIT	2.400	33.587	2.240	11.398	0.494	0.197	0.554	0.095
175.	BASELINE	10.545	133.272	2.998	11.569				
	RETROFIT	7.056	104.579	1.708	9.867	0.325	-0.140	0.581	0.040
246.	BASELINE	6.123	94.725	5.925	10.016				
	RETROFIT	6.955	63.587	2.681	12.783	0.247	-0.129	-0.513	0.306

(1) Test data outlier not used.

(2) Index value not calculated, due to data deficiency.

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 4

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	6.890	44.460	1.630	21.725				
1.	BASELINE	7.064	61.856	3.351	15.425				
	RETROFIT	6.722	33.151	2.860	13.221	0.220	-0.014	0.515	-0.020
10.	BASELINE	9.171	66.670	3.462	13.221				
	RETROFIT	4.957	40.689	1.537	13.691	0.468	-0.021	0.113	0.238
33.	BASELINE	7.923	80.012	2.323	14.238				
	RETROFIT	6.890	57.077	1.511	12.748	0.256	0.180	0.316	0.030
42.	BASELINE	6.150	66.494	3.252	13.691				
	RETROFIT	6.620	33.335	3.354	13.691	0.130	0.114	0.051	0.044
69.	BASELINE	5.275	62.858	3.372	13.221				
	RETROFIT	3.834	39.228	3.555	11.398	0.198	-0.092	0.538	-0.027
96.	BASELINE	8.800	69.714	2.865	14.238				
	RETROFIT	1.179	0.587	1.780	11.745	0.745	0.033	1.022	0.129
96.	BASELINE	7.987	53.662	2.468	14.506				
	RETROFIT	1.985	12.539	1.053	13.691	0.697	0.940	0.611	0.089
175.	BASELINE	6.696	75.958	1.946	14.238				
	RETROFIT	6.382	69.765	1.657	13.691	0.092	-0.112	0.158	0.024
246.	BASELINE	8.658	59.295	4.450	12.783				
	RETROFIT	8.422	45.399	2.806	11.927	0.210	0.173	0.440	-0.030

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 5

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	5.414	86.164	5.290	10.888				
1.	BASELINE	8.348	109.856	2.317	11.044				
	RETROFIT	6.605	64.370	2.318	13.221	0.207	-0.195	-0.385	0.256
42.	BASELINE	14.137	150.511	3.723	10.422				
	RETROFIT	6.504	88.910	3.406	11.927	0.345	0.117	-0.373	0.287
69.	BASELINE	8.001	88.365	3.492	10.888				
	RETROFIT	5.553	70.681	1.863	13.221	0.324	0.200	-0.453	0.286
96.	BASELINE	6.735	74.905	1.895	12.146				
	RETROFIT	3.989	56.824	0.651	11.745	0.435	0.070	0.562	0.078
96.	BASELINE	8.369	104.457	2.573	11.398				
	RETROFIT	5.157	76.366	1.840	10.422	0.313	0.207	0.768	-0.070
175.	BASELINE	8.352	111.726	2.188	11.569				
	RETROFIT	10.103	122.660	1.421	9.742	0.014	0.042	0.627	-0.177
295.	BASELINE	8.348	109.856	2.317	11.044				
	RETROFIT	11.429	87.935	1.730	9.867	0.028	3.261	0.536	-0.603

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 6 (3)

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	5.378	55.209	5.942	12.146				
1.	BASELINE	(1)	72.386	2.924	12.541				
	RETROFIT	5.825	46.290	2.548	14.832	(2)	0.182	-0.294	(2)
10.	BASELINE	6.329	89.964	2.189	12.541				
	RETROFIT	4.586	73.503	1.060	12.146	0.325	0.903	0.295	-0.028
96.	BASELINE	7.463	77.412	1.812	13.452				
	RETROFIT	2.389	51.941	1.194	11.205	0.450	0.405	1.022	-0.092
96.	BASELINE	5.642	72.840	1.763	13.452				
	RETROFIT	2.896	69.859	1.504	10.737	0.225	0.670	1.170	-0.301
245.	BASELINE	4.541	70.782	2.393	16.827				
	RETROFIT	6.169	89.831	1.885	15.123	-0.138	0.895	0.364	-0.311
288.	BASELINE	4.541	70.782	2.393	16.827				
	RETROFIT	4.448	46.128	3.240	14.784	0.005	-0.459	0.342	-0.029

(1) This value invalid due to offscale reading.

(2) Index value not calculated, due to data deficiency.

(3) Device 175 test not included because of invalid data.

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 8 (3)

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	0.0	0.0	0.0	0.0				
1.	BASELINE	5.359	55.782	4.527	11.569				
	RETROFIT	3.158	5.948	3.402	13.691	0.518	0.500	-0.332	0.319
1.	BASELINE	4.150	57.979	3.854	12.575				
	RETROFIT	4.017	12.801	4.527	(1)	0.212	0.140	(2)	(2)
96.	BASELINE	3.585	59.163	2.570	(1)				
	RETROFIT	1.203	19.285	1.215	13.491	0.622	0.251	(2)	(2)
175.	BASELINE	3.689	57.158	3.871	13.980				
	RETROFIT	3.068	13.426	1.683	13.221	0.500	0.852	0.203	0.106
246.	BASELINE	3.690	38.398	3.288	12.783				
	RETROFIT	4.098	39.998	1.376	14.552	0.143	0.176	-0.089	0.082

(1) Test data outlier not used.

(2) Index value not calculated, due to data deficiency.

(3) Device 246 first test not included because of invalid data.

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 9

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	0.0	0.0	0.0	0.0				
1.	BASELINE	4.942	69.819	5.742	12.999				
	RETROFIT	3.629	14.440	4.955	(1)	0.399	0.003	(2)	(2)
1.	BASELINE	4.633	39.881	5.506	13.491				
	RETROFIT	4.312	26.056	4.134	16.124	0.222	0.095	-0.287	0.195
96.	BASELINE	3.462	46.495	4.344	12.999				
	RETROFIT	0.510	7.830	1.819	14.238	0.755	0.262	0.201	0.336
175.	BASELINE	4.042	56.104	3.786	12.575				
	RETROFIT	2.969	11.958	2.184	13.221	0.492	0.116	-0.077	0.286
246.	BASELINE	6.023	97.651	4.253	12.748				
	RETROFIT	5.521	40.636	2.272	13.980	0.378	0.243	0.002	0.181
246.	BASELINE	3.385	43.384	3.922	13.491				
	RETROFIT	3.550	17.005	1.625	(1)	0.382	0.159	(2)	(2)

(1) Test data outlier not used.

(2) Index value not calculated, due to data deficiency.

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 10 (3)

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	10.131	407.292	0.680	8.601				
1.	BASELINE	7.678	74.862	6.892	12.340				
	RETROFIT	9.907	5.147	6.925	15.374	0.212	0.152	-0.423	0.220
1.	BASELINE	5.979	42.038	5.093	14.238				
	RETROFIT	5.810	11.313	6.064	14.238	0.190	-0.001	0.137	0.069
96.	BASELINE	4.632	43.654	5.142	10.016				
	RETROFIT	1.347	9.782	1.982	13.221	0.700	0.199	-0.464	0.504
175.	BASELINE	4.682	40.820	3.821	14.238				
	RETROFIT	3.792	15.887	1.660	11.569	0.456	0.169	0.627	0.057
246.	BASELINE	4.701	45.556	3.416	(1)				
	RETROFIT	3.841	24.860	1.507	13.980	0.399	-0.027	(2)	(2)

(1) Test data outlier not used.

(2) Index value not calculated, due to data deficiency.

(3) Device 246 first test not included because of invalid test.

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 11

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	12.705	313.340	2.564	12.340				
1.	BASELINE	7.358	99.558	3.501	12.999				
	RETROFIT	5.617	25.862	4.479	14.506	0.232	0.007	-0.143	0.173
1.	BASELINE	8.656	109.923	3.176	10.737				
	RETROFIT	4.237	40.509	5.049	13.731	0.184	0.063	-0.574	0.260
96.	BASELINE	4.084	64.446	2.826	13.980				
	RETROFIT	0.294	0.297	1.156	15.425	0.838	0.293	0.201	0.379
175.	BASELINE	3.425	50.914	2.339	12.146				
	RETROFIT	2.586	12.868	2.266	12.999	0.341	0.193	-0.130	0.204
246.	BASELINE	7.615	125.381	4.101	12.340				
	RETROFIT	6.240	85.972	2.233	12.999	0.317	-0.053	0.100	0.160
246.	BASELINE	5.333	89.387	2.899	11.569				
	RETROFIT	2.878	24.290	1.450	15.794	0.563	0.028	-0.565	0.479

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 12

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	8.654	231.383	2.302	13.452				
1.	BASELINE	8.067	72.944	3.287	15.425				
	RETROFIT	4.361	36.179	3.220	15.740	0.328	0.054	0.092	0.154
1.	BASELINE	6.455	56.033	2.746	17.267				
	RETROFIT	6.328	26.554	3.663	12.999	0.071	0.154	0.803	-0.211
96.	BASELINE	3.547	36.343	3.275	14.552				
	RETROFIT	0.492	1.505	1.642	13.980	0.773	0.098	0.562	0.267
175.	BASELINE	4.359	38.516	2.834	13.221				
	RETROFIT	2.889	12.700	1.887	10.589	0.447	0.057	0.717	0.042
246.	BASELINE	8.177	72.434	3.387	14.784				
	RETROFIT	7.360	50.623	2.014	14.238	0.269	-0.071	0.335	0.068
246.	BASELINE	5.268	55.706	2.593	16.468				
	RETROFIT	3.150	25.930	1.497	14.506	0.453	0.168	0.531	0.083

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Continued)

CAR NUMBER 16

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	0.0	0.0	0.0	0.0				
175.	BASELINE	5.175	46.815	5.028	16.124				
	RETROFIT	3.113	12.448	2.828	11.957	0.523	0.450	0.816	0.002

CAR NUMBER 17

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	7.657	238.259	0.498	8.715				
246.	BASELINE	10.884	163.370	3.155	9.367				
	RETROFIT	10.778	146.601	1.312	10.565	0.232	0.084	-0.180	0.172

CAR NUMBER 18 (1)

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(1) Device 246 test not included because of invalid data.

Table E-2. ANAHEIM AND DETROIT RETROFIT DEVICE TEST RESULTS (Concluded)

CAR NUMBER 19 (3)

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	0.0	0.0	0.0	0.0				
1.	BASELINE	10.812	76.124	1.685	20.032				
	RETROFIT	5.788	32.805	1.481	(1)	0.385	0.456	(2)	(2)

CAR NUMBER 20 (3)

DEVICE	TEST	HC	CO	NOX	FUEL,MPG	EMISSION INDEX	DRIVEABILITY INDEX	COST INDEX	PERFORMANCE INDEX
	AS REC'D	3.313	76.364	2.272	25.708				
1.	BASELINE	6.120	37.497	2.188	21.227				
	RETROFIT	1.762	5.442	2.034	15.123	0.546	0.293	0.803	0.041

(1) Test data outlier not used.

(2) Index value not calculated, due to data deficiency.

(3) Device 246 test not included because of invalid data.

APPENDIX F

BASELINE AND RETROFIT EMISSION LEVELS IN GRAMS/MILE FOR DEVICES TESTED IN RETROFIT PROGRAM BY 1972 FEDERAL TEST PROCEDURE

CAR NO. AND LOCATION(1)	MAKE AND CID	TEST (2)	HYDROCARBONS		CARBON MONOXIDE		NITROGEN OXIDES	
			BASELINE	RETROFIT	BASELINE	RETROFIT	BASELINE	RETROFIT
1. Device 1: Air Bleed to Intake Manifold								
1A	65 Chev 194	1	15.10	12.44	135.37	143.93	0.84	1.27
2A	65 Ford 289	1	6.53	4.54	73.65	50.53	4.45	4.92
3A	65 Ply 318	1	6.12	6.62	83.70	33.00	5.74	4.79
4A	65 Chev 327	1	7.06	6.72	61.86	33.15	3.35	2.86
5A(5)	65 Ford 390	1	8.35	6.61	109.86	64.37	2.32	2.32
6A	61 Chev 283	1	(3)	5.83	72.39	46.29	2.92	2.55
19A	65 VW 92	1	10.81	5.79	76.12	32.81	1.69	1.48
8T	65 Ford 289	1	5.36	3.16	55.78	5.95	4.53	3.40
		2	4.15	4.02	57.96	12.80	3.84	4.51
9T	65 Ply 318	1	4.94	3.63	69.81	14.44	5.77	4.97
		2	4.63	4.31	39.88	26.06	5.48	4.13
10T	65 Chev 327	1	7.68	9.91	74.87	5.15	6.88	6.90
		2	5.98	5.81	42.04	11.31	5.10	6.06
11T	65 Ford 390	1	7.36	5.62	99.55	25.86	3.48	4.47
		2	8.66	4.24	109.96	40.51	3.20	5.04
12T	61 Chev 283	1	8.07	4.36	72.94	36.18	3.34	3.22
		2	6.45	6.33	56.03	26.55	2.75	3.66
20T	65 VW 92	1	6.12	1.76	37.50	5.44	2.18	2.03
2. Device 96: Catalytic Converter with Distributor Vacuum Advance Disconnect								
1A		1(4)	11.09	1.65	85.06	18.42	2.87	0.67
		2(4)	8.12	3.93	75.39	17.01	1.72	1.45
2A		1(4)	8.85	0.69	121.83	5.95	2.83	0.99
		2(4)	10.36	2.53	149.77	55.09	1.29	0.76
3A		1	6.62	4.36	101.94	89.61	3.33	1.04
		2(4)	7.06	2.41	68.90	33.59	3.24	2.26
4A		1(4)	8.80	1.17	69.76	0.57	2.87	1.78
		2(4)	7.98	1.99	53.65	12.53	2.49	1.08
5A		1	6.73	4.00	74.88	56.80	1.90	0.64
		2	8.37	5.16	104.45	76.38	2.56	1.84
6A		1(4)	7.47	2.38	77.44	51.99	1.82	1.19
		2	5.65	2.90	72.81	69.86	1.72	1.52
8T		1	3.59	1.20	59.16	19.29	2.61	1.26
9T		1	3.46	0.51	46.50	7.83	4.34	1.82
10T		1	4.63	1.35	43.65	9.78	5.14	1.97
11T		1(4)	4.08	0.29	64.45	0.30	2.83	1.20
12T		1(4)	3.55	0.49	36.34	1.51	3.28	1.64

APPENDIX F

BASELINE AND RETROFIT EMISSION LEVELS IN GRAMS/MILE FOR DEVICES TESTED IN RETROFIT PROGRAM BY 1972 FEDERAL TEST PROCEDURE (CONT)

CAR NO. AND LOCATION(1)	MAKE AND CID	TEST (2)	HYDROCARBONS		CARBON MONOXIDE		NITROGEN OXIDES	
			BASELINE	RETROFIT	BASELINE	RETROFIT	BASELINE	RETROFIT
3. Device 175: Ignition Timing Modification with Lean Idle Adjustment								
1A		1	10.67	9.17	71.56	63.41	2.20	1.24
3A		1	10.55	7.06	133.27	104.58	3.00	1.71
4A		1	6.70	6.38	75.96	69.77	1.95	1.66
5A		1	8.35	10.10	111.73	122.66	2.19	1.42
6A		1	5.57	6.09	(3)	98.01	1.29	1.34
8T		1	3.69	3.07	57.16	13.43	3.87	1.68
9T		1	4.04	2.97	56.10	11.96	3.79	2.18
10T		1	4.68	3.79	40.82	15.89	3.82	1.66
11T		1	3.43	2.59	50.92	12.87	2.34	2.27
12T		1	4.36	2.89	38.52	12.70	2.88	1.89
16T		1	5.18	3.11	46.82	12.45	5.03	2.83
4. Device 246: Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect								
1A		1	(3)	(3)	202.99	177.78	0.65	0.26
2A		1	8.81	6.38	106.46	70.61	4.60	2.88
3A		1	6.12	6.96	94.73	63.59	5.93	2.70
4A		1	8.66	8.42	59.29	45.40	4.45	2.81
17A		1	10.88	10.78	163.37	146.60	3.16	1.31
18A		1	(3)	8.68	85.86	92.98	1.46	0.81
19A		1	7.79	6.59	51.78	45.79	1.57	1.16
8T		1	3.06	(3)	83.54	(3)	6.12	(3)
		2	3.69	4.10	38.40	40.00	3.24	1.37
9T		1	6.02	5.52	97.62	40.64	4.29	2.25
		2	3.38	3.55	43.38	17.00	3.87	1.62
10T		1	3.95	9.80	52.52	47.42	(3)	3.00
		2	4.70	3.84	45.56	24.86	3.42	1.51
11T		1	7.61	6.24	125.34	85.97	4.12	2.28
		2	5.33	2.88	89.38	24.29	2.86	1.45
12T		1	8.17	7.36	72.41	50.62	3.42	2.02
		2	5.27	3.15	55.71	25.95	2.56	1.50
20T		1	5.32	4.82	34.11	43.18	1.75	(3)
5. Device 10: Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect								
4A		1	9.17	4.96	66.67	40.69	3.46	1.54
6A		1	6.33	4.59	89.96	73.50	2.19	1.06
6. Device 33: Carburetor Modification, Main Jet Differential Pressure Main								
2A		1	10.55	4.99	181.80	67.56	1.02	2.26
4A		1	7.92	6.89	80.01	57.08	2.32	1.51
7. Device 42: Air Bleed to Intake Manifold								
4A		1	6.15	6.62	66.49	33.34	3.25	3.35
5A		1	14.14	6.50	150.50	88.94	3.72	3.41

APPENDIX F

BASELINE AND RETROFIT EMISSION LEVELS IN GRAMS/MILE FOR DEVICES TESTED IN RETROFIT PROGRAM BY 1972 FEDERAL TEST PROCEDURE (CONCL)

CAR NO. AND LOCATION(1)	MAKE AND CID	TEST (2)	HYDROCARBONS		CARBON MONOXIDE		NITROGEN OXIDES	
			BASELINE	RETROFIT	BASELINE	RETROFIT	BASELINE	RETROFIT
8.	Device 69: Electronic Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Mod.							
3A		1	5.49	3.34	69.55	48.59	5.14	3.49
4A		1	5.28	3.83	62.86	39.23	3.37	3.56
5A		1	8.00	5.55	88.37	70.68	3.49	1.86
9.	Device 245: Variable Camshaft Timing							
6A(6)		1	4.54	6.17	70.78	89.83	2.39	1.89
10.	Device 288: Carburetor Main Discharge Nozzle Modification							
2A		1	6.59	6.18	117.45	71.78	3.28	3.34
6A		1	4.54	4.45	70.78	46.13	2.39	3.24
11.	Device 295: Carburetor with Variable Venturi							
5A		1	8.35	11.43	109.86	87.94	2.32	1.73

(1) A - Anaheim, California; T - Taylor Michigan.
(2) Test 2 is a replicate for Test 1.
(3) Measured test data invalid.
(4) Air pump installed and operating, as per developer's request.
(5) Baseline invalid due to blown head gasket. Baseline following device removal was used.
(6) No baseline test performed. Baseline following device removal was used.

APPENDIX G

MEAN EMISSION LEVELS FOR RETROFIT DEVICES EVALUATED BASED ON EPA AND RETROFIT DEVELOPER TEST DATA

DEVICE NO.	DESCRIPTION	HYDROCARBONS		CARBON MONOXIDE		NITROGEN OXIDES		DATA SOURCE (2)	NO. OF TESTS	TEST TYPE
		BASE-LINE	RETRO-FIT	BASE-LINE	RETRO-FIT	BASE-LINE	RETRO-FIT			
23	Electronic Ignition Unit	6.51 gm/mi	6.32 gm/mi	93.81 gm/mi	109.08 gm/mi	2.14 gm/mi	3.33 gm/mi	E	1	1972 FEDERAL TEST PROCEDURE (CVS)
24	Heavy Duty Positive Crankcase Control Valve with Air Bleed	4.63 gm/mi	4.45 gm/mi	50.36 gm/mi	44.03 gm/mi	6.59 gm/mi	6.10 gm/mi	E	6(3)	
52	LPG Conversion	3.18 gm/mi	0.60 gm/mi	19.06 gm/mi	2.83 gm/mi	8.14 gm/mi	2.86 gm/mi	E	18	
95	Ignition Spark Modification	6.00 gm/mi	7.60 gm/mi	92.00 gm/mi	108.00 g/m	1.60 gm/mi	2.10 gm/mi	E	1	
100	Turbocharger	3.50 gm/mi	3.00 gm/mi	41.00 gm/mi	36.00 gm/mi	2.50 gm/mi	2.30 gm/mi	E	1	
172	Intake Manifold Modification	3.4 gm/mi	3.9 gm/mi	43 gm/mi	43 gm/mi	3.7 gm/mi	2.7 gm/mi	E	1	
292	Catalytic Converter	6.6 gm/mi	5.20 gm/mi	65.0 gm/mi	75.00 gm/mi	3.9 gm/mi	2.3 gm/mi	E	1	
294	Exhaust Gas Recirculation with Carburetor Modification	3.80 gm/mi	6.80 gm/mi	67.00 gm/mi	60.00 gm/mi	4.00 gm/mi	2.80 gm/mi	E	1	
418	Air Bleed to Intake Manifold	4.28 gm/mi	3.93 gm/mi	54.7 gm/mi	33.2 gm/mi	5.4 gm/mi	5.3 gm/mi	E	3(4)	
460	Compressed Natural Gas Dual-Fuel Conversion	3.00 gm/mi	3.00 gm/mi	21.00 gm/mi	25.00 gm/mi	2.80 gm/mi	4.60 gm/mi	E	1	
462	Air Bleed to Intake and Exhaust Manifolds	7.74 gm/mi	5.84 gm/mi	79.0 gm/mi	69.0 gm/mi	3.03 gm/mi	3.9 gm/mi	E	3(13)	
464(2)	Methanol Fuel Conversion with Catalytic Converter	0.90 gm/mi	0.45 gm/mi	8.10 gm/mi	6.82 gm/mi	8.8 gm/mi	0.24 gm/mi	E	6(11)	
465	Fuel Additive	9.50 gm/mi	8.33 gm/mi	112.30 gm/mi	101.19 gm/mi	4.15 gm/mi	3.81 gm/mi	E	1	
466	LPG-Gasoline Dual-Fuel Conversion	3.18 gm/mi	2.58 gm/mi	30.13 gm/mi	8.93 gm/mi	3.43 gm/mi	2.43 gm/mi	E	6	
No Baseline Given for the Following Devices:										
56	Crankcase Blowby and Idle Air Bleed Modification	(5)	5.20 gm/mi	(5)	45.72 gm/mi	(5)	3.23 gm/mi	E	1	
93	Catalytic Converter with Exhaust Gas Recirculation, Spark Modification, and Lean Idle Mixture	(5)	0.90 gm/mi	(5)	9.10 gm/mi	(5)	1.40 gm/mi	E	6	
315	Closed Blowby Control System	(5)	304 ppm	(5)	1.55 %	(5)	1123 ppm	D	1	
459	LPG Conversion with Deceleration Unit	(5)	1.04 gm/mi	(5)	3.77 gm/mi	(5)	1.95 gm/mi	E	1	
461	LPG Conversion with Exhaust Reactor Pulse Air Injection and Exhaust Gas Recirculation	(5)	0.87 gm/mi	(5)	3.07 gm/mi	(5)	0.30 gm/mi	E	1	
463	Rich Thermal Reactor with Exhaust Gas Recirculation and Spark Retard	(5)	0.13 gm/mi	(5)	5.33 gm/mi	(5)	0.60 gm/mi	E	3	
468	Lean Thermal Reactor with Exhaust Gas Recirculation	(5)	0.89 gm/mi	(5)	8.60 gm/mi	(5)	1.37 gm/mi	D	5(15)	
469	Rich Thermal Reactor with Exhaust Gas Recirculation and Particulate Control	3.07 gm/mi	0.060 gm/mi	37.35 gm/mi	20.74 gm/mi	3.24 gm/mi	1.12 gm/mi	E	2	EPA(14) 9X7 CVS

APPENDIX G

MEAN EMISSION LEVELS FOR RETROFIT DEVICES EVALUATED BASED ON EPA AND RETROFIT DEVELOPER TEST DATA (CONT)

DEVICE NO.	DESCRIPTION	HYDROCARBONS		CARBON MONOXIDE		NITROGEN OXIDES		DATA SOURCE (2)	NO. OF TESTS	TEST TYPE
		BASE-LINE	RETRO-FIT	BASE-LINE	RETRO-FIT	BASE-LINE	RETRO-FIT			
36	Fuel Conditioning by Exposure to Electromagnetic Field	7.12 gm/mi	8.02 gm/mi	48.80 gm/mi	50.00 gm/mi	gm/mi	gm/mi	E	11(7)	7-CYCLE, 7-MODE COLD START
57	Air Bleed with Exhaust Gas Recirculation and Vacuum Advance Disconnect	10.8 gm/mi	4.78 gm/mi	85.62 gm/mi	40.85 gm/mi	2.23 gm/mi	1.19 gm/mi	D	1	
59	Three-Stage Exhaust Gas Control System	811 ppm	552	4.65 %	3.80 %	602	535 ppm	D	1	
62	Catalytic Converter	607 ppm	343 ppm	4.14 %	3.54 %	692 ppm	641 ppm	E	1	
164	Exhaust Gas Filter	149 ppm	134 ppm	1.31 %	1.28 %	984 ppm	983 ppm	D	1	
182(10)	Fuel and Oil Additives	(10)	(10)	(10)	(10)	(10)	(10)	D		
244	Rich Thermal Reactor	(10)	(10)	(10)	(10)	(10)	(10)	E	(5)	
117	Carburetor Modification with Vacuum Advance Disconnect	439 ppm	248 ppm	2.78 %	2.16 %	942 ppm	616 ppm	D	4	
322	Exhaust Gas Backpressure Valve	4.01 gm/mi	6.87 gm/mi	53.85 gm/mi	50.16 gm/mi	1.62 gm/mi	1.83 gm/mi	E	1	
384	Air-Fuel Mixture Diffuser	579 ppm	346 ppm	7.14 %	5.74 %	415 ppm	293 ppm	D	1	
401	Air-Vapor Bleed to Intake Manifold	1.76 gm/mi	1.33 gm/mi	23.73 gm/mi	15.63 gm/mi	5.64 gm/mi	7.39 gm/mi	D	1	
425	Exhaust Gas Afterburner	500 ppm	17 ppm	9.37 %	0.26 %	(5)	(5)	D	1(8)	
430	Induction Modification	6.26 gm/mi	3.64 gm/mi	62.5 gm/mi	55.5 gm/mi	4.22 gm/mi	2.62 gm/mi	D	2	
458	Air Bleed to Intake Manifold	2.70 gm/mi	2.80 gm/mi	28.00 gm/mi	26.00 gm/mi	3.70 gm/mi	4.00 gm/mi	E		
No Baseline Given for the Following Devices:										
22	Electronic Fuel Injection	(5)	2.30 gm/mi	(5)	22.00 gm/mi	(5)	1.50 gm/mi	E	1	
31	Thermal Reaction by Turbine Blower Air Injection	(5)	258 ppm	(5)	1.12 %	(5)	(5)	D	6(8)	
160	Closed or Open Blowby Control System with Filter	(5)	0.37 gm/mi	(5)	8.36 gm/mi	(5)	2.32 gm/mi	D	1	
165(11)	Exhaust Gas Afterburner/Recirculation with Blowby and Fuel Evaporation Recirculation	(5)	326 ppm	(5)	0.97 %	(5)	704 ppm	D	1	7-MODE HOT START CYCLES
170	Closed Blowby Control System	440 ppm	395 ppm	3.50 %	4.40 %	1520 ppm	810 ppm	D	1	
279	Fuel Conditioner	147 ppm	142 ppm	0.53 %	0.40 %	1508 ppm	1442 ppm	D	1	
296	Ignition Timing and Spark Modification	196 ppm	180 ppm	3.42 %	3.27 %	279 ppm	290 ppm	[illegible]	1	
325	Air-Vapor Bleed to Intake Manifold	494 ppm	347 ppm	3.14 %	2.03 %	876 ppm	791 ppm	D	7	
427	Closed or Open Blowby Control System with Filter	236 ppm	223 ppm	0.74 %	0.38 %	2194 ppm	2183 ppm	D	2	
433	Air-Vapor Bleed to Intake Manifold	494 ppm	347 ppm	3.14 %	2.03 %	876 ppm	791 ppm	D	7	
308	Exhaust Gas Afterburner	143 ppm	167 ppm	1.70 %	1.70 %	317 ppm	283 ppm	D	3(9)	STEADY STATE
457(10)	Water Injection	(5)	(5)	(5)	(5)	1918 ppm	479 ppm	E	10 (9)	

APPENDIX G

MEAN EMISSION LEVELS FOR RETROFIT DEVICES EVALUATED BASED ON EPA AND RETROFIT DEVELOPER TEST DATA (CONCL)

DEVICE NO.	DESCRIPTION	HYDROCARBONS		CARBON MONOXIDE		NITROGEN OXIDES		DATA SOURCE (2)	NO. OF TESTS	TEST TYPE
		BASE-LINE	RETRO-FIT	BASE-LINE	RETRO-FIT	BASE-LINE	RETRO-FIT			
259	Photocell-Controlled Ignition System	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	NO TEST DATA AVAILABLE
268	Capacitive Discharge Ignition	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	
282	LP Gas Injection	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	
408	Exhaust Gas and Blowby Recirculation with Intake Vacuum Control and Turbulent Mixing	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	
440	Air-Fuel Mixture Deflection Plate	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	
467	Fuel Evaporation Control System	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	

(1) The values in this table represent the mean of the individual baseline and retrofit device test results. The number of baseline tests is not always equal to the number of retrofit device tests.

(2) R = Retrofit Test Program
D = Developer Supplied Data
E = Environmental Protection Agency (data references are presented in Volume II).

(3) Six baseline and five device tests for HC and CO; three baseline and four device tests for NO_x.

(4) 16 baseline and 11 device tests on 3 vehicles.

(5) Unknown.

(6) 4 Tests for HC and CO, 1 Test for NO_x.

(7) 1 Baseline Test, 11 Retrofit Tests for HC and CO Only.

(8) HC and CO Only.

(9) Different Steady State Speeds.

(10) Emission levels not reported by developer. Only percent reduction given.

(11) One baseline test and 6 device tests.

(12) Qualitative driveability and fuel consumption runs only.

(13) Ten baseline and 9 device 1972 Federal Tests.

(14) EPA Interim 9-Cycle, 7-Mode CVS Emission Test Procedure (refer to Volume II, Reference 16).

(15) No air injection.

APPENDIX H

WELCH'S APPROXIMATE t SOLUTION OF THE FISHER-BEHRENS PROBLEM

The Fisher-Behrens problem is the testing of the hypothesis that the means of two normal populations are equal regardless of the size of their respective variances based on two samples, one drawn from each population.

A brief description of Welch's approximate t solution of the Fisher-Behrens problem(1) is presented. Letting subscripts 1 and 2 represent the two populations, the corresponding samples of size n_1 and n_2 have means $\bar{r}_1$ and $\bar{r}_2$ and variance estimates s_1^2 and s_2^2 with ν_1 and ν_2 degrees of freedom. The squared standard deviation of the difference d between the two means is $s_d^2 = s_{\bar{r}_1}^2 + s_{\bar{r}_2}^2$; where, $d = \bar{r}_1 - \bar{r}_2$. A quantity c is defined to be:

$$c = \frac{s_{\bar{r}_1}^2}{s_d^2} = \frac{s_{\bar{r}_1}^2}{\left(s_{\bar{r}_1}^2 + s_{\bar{r}_2}^2\right)}$$

then the Welch t solution test statistic is:

$$t = \frac{(d-\delta)}{s_d}$$

where the population mean difference is tested against a value δ, here taken to be zero. The Student t tables are used with ν degrees freedom from:

$$\frac{1}{\nu} = \frac{c^2}{\nu_1} + \frac{(1 - c)^2}{\nu_2}$$

This is usually fractional. The t table should be interpolated using $1/\nu$ as the argument.

In Table H-1, a sample calculation from data in Table 6-1 of Section 6 is presented for the comparison of Test 1 and Test 2 for CO using Device 1 at the Taylor test center. The statistical evidence is clear that there is a significant CO reduction, but all one can say about its magnitude is that it is somewhere between 22 and 80 percentage reduction, without a well defined confidence level.

The results of the Welch test, t = 1.835 with 8.18 degrees of freedom, indicate that there is no difference in means between the populations corresponding to Taylor Test 1 and Test 2 (an F test, F = 299.165/237.85 = 1.258 shows that the population variances can also be considered alike, since for 5 and 4 degrees of freedom, the 10 and 5 percent F test points are 4.05 and 6.26, respectively).

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(1) B.L. Welch, Biometrika 34, 28-35 (Jan. 1947)

In the emission reduction confidence calculations, the t values of 12.48 with 5 degrees of freedom and 7.79 with 4 degrees of freedom show that the means for both Test 1 and Test 2 are significantly different from zero. This is confirmed by the 90 percent confidence limits of 66 to 91 percentage reduction and 44 to 77 percentage reduction. When, following the Welch test, Tests 1 and 2 are combined into a single set with 11 values for Taylor, the average percentage reduction is 70.28 and t = 12.83 with 10 degrees of freedom. The 90 percent confidence limits are 60 to 80 percentage reduction.

The next stage is a Welch test of the combined Taylor results (Tests 1 and 2 combined) against those at Anaheim. The calculations are not given here. It turns out that the Anaheim CO mean (38 percentage reduction) is significantly different from the Taylor mean 70 with t = 3.21 (11.005 degrees of freedom). The Anaheim and Taylor results cannot be statistically combined and two separate conclusions are presented. The Student t test results and the 90 percent confidence limits for the Anaheim and Taylor (Test 1 and 2) data are:

t test results	90 percent confidence limits (% reduction)
Anaheim t = 4.54 with 6 df	22 to 54
Taylor t = 12.99 with 10 df	60 to 80

Where df = degrees of freedom.

Table H-1. SAMPLE CALCULATIONS FOR WELCH TEST OF DEVICE 1, CARBON MONOXIDE

STATISTIC	TAYLOR TEST NO. 1	TAYLOR TEST NO. 2	REMARKS
1. **Emission Reduction Confidence Limits,**			
n	6	5	Sample size
ΣR	471.6	301.5	
$\bar{r}$	78.60	60.30	Mean reduction %
ΣR^2	38257.00	19377.11	
$(\Sigma R)^2/n$	37067.76	18180.45	
$\Sigma (R-\bar{r})^2$	1189.25	1196.6596	
df	5	4	Degrees of freedom
s^2	237.85	299.1649	Variance
s	15.42	17.296	Std. deviation
s^2/n	36.629	59.833	Variance of mean
$s_{\bar{r}}$	6.295	7.735	Std. Devn. of mean
t	78.6/6.295 = 12.48	60.30/7.735 = 7.79	t-value for testing Mean = 0.0
$t_{10\%}$	2.015	2.132	Student t, two-sided 10% point
$t_{10\%}s$	12.68	16.49	
90% limits	65.9 to 91.3	43.81 to 76.79	Conf. limits of mean

2. **For the Welch test,**

$$d = \bar{r}_1 - \bar{r}_2 = 78.60 - 60.30 = 18.30$$

$$s_d^2 = 39.6294 + 59.833 = 99.462$$

$$s_d = 9.973$$

$$c = 39.629/99.462 = 0.3984$$

$$\frac{1}{\nu} = \frac{(0.3984)^2}{5} + \frac{(0.6016)^2}{4}$$

$$\nu = 8.18 \text{ df}$$

$$t = d/s_d = 18.30/9.973 = 1.8349$$

APPENDIX J

SENSITIVITY ANALYSIS OF RETROFIT PROGRAM DRIVEABILITY AND COST INDEXES

A sensitivity analysis was performed on the Driveability and Cost Indexes. The purpose of this analysis was to determine the sensitivity of the indexes to changes in the input parameters due to either the installation of a retrofit device or due to test measurement errors.

A sensitivity analysis determines the impact of a change in one measurement upon the index while keeping all other input parameters constant. Using this approach it was assumed that each parameter of the Driveability and Cost Indexes was independent of one another. On this basis the sensitivity due to test measurement errors and/or to the performance differential resulting from the installation of a retrofit device can be determined by partial differentiation. An input change of 20 percent in the assumed value of each Driveability and Cost Index term was used for calculating the sensitivity of that term. This change was then compared to the overall index term so that the sensitivity of the parameter could be evaluated.

A summary discussion of the sensitivity analysis is presented in paragraph 6.2.2 for the Driveability Index and paragraph 6.3.4 for the Cost Index.

1.1 DRIVEABILITY INDEX

The overall general Driveability Index (DI) equation in terms of rating points used in this study was:(1)

$$
\begin{aligned}
DI = S_2 \Bigg[& \left(\alpha_1 \sum_1^3 \Delta D_{RI} + \alpha_2 \sum_1^3 \Delta D_{STI} + \alpha_3 \sum_1^{60} \Delta D_{STM} \right. \\
& \left. + \alpha_4 \sum_1^{60} \Delta D_H + \alpha_5 \Delta D_D + \alpha_6 \sum_1^{60} \Delta D_S + \alpha_7 \sum_1^{60} \Delta D_{SU} \right)_{cold} \\
& + \left(\alpha_8 \sum_1^2 \Delta D_{RI} + \alpha_9 \sum_1^{20} \Delta D_{STM} + \alpha_{10} \sum_1^{20} \Delta D_H \right. \\
& \left. + \alpha_{11} \sum_1^{20} \Delta D_D + \alpha_{12} \sum_1^{20} \Delta D_S + \alpha_{13} \sum_1^{20} \Delta D_{SU} \right)_{hot} \\
& + \left(\alpha_{14} \Delta D_{TN} \right)_{cold} + \left(\alpha_{15} \Delta D_{TN} \right) hot + \alpha_{16} \Delta D_A \Bigg] \Bigg/ \sum_1^{16} \alpha_i
\end{aligned}
$$

Where: S_2 = Scaling factor which is a constant and is deleted from the subsequent analysis because it cancels out.

---

(1) All basic equations are from Section 3 of this volume.

The summation signs, $\sum$, indicate the total number of driveability observations taken during the running of a test.

The relative sensitivity of the DI, with respect to each one of the 16 driveability terms, is determined by the weighting factors of α_1, α_2, α_3 .... α_{16}, respectively. The individual weighting factors are tabulated in Section 3. The sum of these weighting factors is 11.933. To calculate a nominal Driveability Index, the following differences in rating points between the retrofit and baseline tests were assumed:

Cold Start		Hot Start	
1	$\Delta D_{RI} = 1$	8	$\Delta D_{RI} = 1$
2	$\Delta D_{STI} = 1$	9	$\Delta D_{STM} = 1$
3	$\Delta D_{STM} = 1$	10	$\Delta D_{H} = 1$
4	$\Delta D_{H} = 1$	11	$\Delta D_{D} = 1$
5	$\Delta D_{D} = 1$	12	$\Delta D_{S} = 1$
6	$\Delta D_{S} = 1$	13	$\Delta D_{SU} = 1$
7	$\Delta D_{SU} = 1$		

14 $\Delta D_{TN} = 3$ Cold Start

15 $\Delta D_{TN} = 3$ Hot Start

16 $\Delta D_{A} = 4.5$ Hot Start

Using the above assumptions and the weighting factors listed in Section 3, the nominal general driveability index is:

$$DI = \frac{(4.933)\ (1) + (2)\ (3) + (5)\ (4.5)}{11.933} = 3.0$$

If one assumes that each one of the 16 driveability terms are independent of one another, the sensitivity of DI with respect to the deviation of each term may be calculated by partial differentiation.

1.1.1 Effects of Basic Cold and Hot Driveability Characteristics

The most sensitive case is represented by the rough idle (hot driveability) term with a weighting factor $\alpha_8 = 2.0$. Partial differentiation of this term is:

$$\frac{\partial (DI)}{\partial (\Delta D_{RI})_{Hot}} = \frac{2.0}{11.933} = 0.168$$

For a 20 percent deviation of an assumed average rating point change of 1.0, the deviation of the rough idle term is:

$$(0.168)\ (0.2) = 0.0336$$

Comparing this deviation to the nominal Driveability Index (DI) of 3, the variation of the rough idle term is:

$$\frac{0.0336}{3.0} \times (100) = 1.1 \text{ percent}$$

1.1.2 Effects of Cold and Hot Start Cranking Time

Following the logic developed in previous paragraphs,

$$\frac{\partial \, DI}{\partial \, (\Delta D_{TN})_{\substack{\text{Cold}\\ \text{or}\\ \text{Hot}}}} = \frac{1}{11.933} = 0.0838$$

For a 20 percent variation of an assumed average start time differential (ΔD_{TN}) of 3, the start time term deviation is:

$$(0.2)\ (3)\ (0.0838) = 0.0503$$

The variation of DI due to a 20 percent deviation of (ΔD_{TN}) hot is:

$$\frac{0.0503}{3} \times (100) = 1.7 \text{ percent}$$

1.1.3 Effect of Acceleration Time

Following the previous logic,

$$\frac{\partial DI}{\partial (\Delta D_A)} = \frac{5}{11.933} = 0.419$$

For a 20 percent variation of an assumed average acceleration time differential (ΔD_A) of 4.5, the acceleration term deviation is:

$$(0.2)\ (4.5)\ (0.419) = 0.375$$

The variation of DI due to 20 percent deviation of (ΔD_A) is:

$$\frac{0.375}{3} \times (100) = 12.5 \text{ percent}$$

2.2 COST INDEX

The overall cost equation in terms of dollars per mile driven is:

$$\text{Cost Index (CI)} = \text{Initial Cost} + \text{Recurring Cost}$$

$$= S_3 \left[\frac{C_{DI}}{MMBTF} + \left\{ \left(\frac{MTTR}{MMBPF} + \frac{MTTM}{MMBM} \right) L_C + \frac{C_{RP}}{MMBPF} + \frac{C_{MP}}{MMBM} + \left(\sigma_D - \sigma_B \right) G_C \right\} \right]$$

Where: S_3 = The scaling factor which is a constant and is deleted from subsequent analysis because it cancels out.

The following set of assumptions was used for calculating a nominal **Cost Index:**

C_{DI}	=	\$85	Initial cost of device
L_C	=	\$12.50/hr	Labor rate
C_{RP}	=	\$20.00	Average cost of repair parts
C_{MP}	=	\$2.00	Average cost of maintenance parts
G_C	=	\$0.35/gallon	Gasoline cost
MMBTF	=	50,000 miles	Mean-miles-before-total-failure
MMBPF	=	25,000 miles	Mean-miles-before-partial-failure
MMBM	=	12,000 miles	Mean-miles-before-maintenance
MTTR	=	1 hr	Mean-time-to-repair
MTTM	=	0.5 hr	Mean-time-to-maintain
$\Delta \sigma$	=	0 gallons/mile (no change)	Fuel consumption change

Using these assumptions the nominal Cost Index (CI) is:

$$CI = 100\left[\frac{85}{50{,}000} + \left\{\left(\frac{1}{25{,}000} + \frac{0.5}{12{,}000}\right)(12.50) + \frac{20}{25{,}000} + \frac{2}{12{,}000} + (0)(0.35)\right\}\right]$$

$$CI = 0.360/100 \text{ miles}$$

It is reasonable to assume that all the elements, C_{DI}, C_{RP}, C_{MP}, L_C, G_C, MMBTF, MMBPF, MMBM, MTTR, and MTTM, are independent of one another. On the basis of this assumption, the expression of the sensitivity of the CI may be approached by partial differentiation.

2.2.1 Effect of MMBTF (Mean-Miles-Before-Total-Failure)

$$\frac{\partial CI}{\partial MMBTF} = \left(C_{DI}\right)\frac{(-1)}{(MMBTF)^2}$$

$$\left|\frac{\partial CI}{\partial MMBTF}\right| = \frac{C_{DI}}{(MMBTF)^2}$$

Therefore:

$$\frac{\partial CI}{\partial MMBTF} = \frac{\$85.00}{(50{,}000 \text{ miles})^2} = \$3.4 \times 10^{-6}/100 \text{ mile}^2$$

For a 20 percent deviation of the MMBTF, which is 10,000 miles, the variation of initial cost may be estimated:

$$10{,}000 \text{ miles } (3.34 \times 10^{-6}/100 \text{ miles}^2) = 3.4 \times 10^{-2}/100 \text{ miles}$$

Comparing this figure to the nominal CI ($0.360/100 miles), the variation of CI due to a 20 percent deviation of MMBTF is:

$$\frac{\$0.034/100 \text{ miles}}{\$0.360/100 \text{ miles}} \times (100) = 9.5 \text{ percent}$$

2.2.2 Effect of MMBPF (Mean-Miles-Before-Partial-Failure)

Following the same logic of the previous paragraphs,

$$\frac{\partial CI}{\partial MMBPF} = \frac{MTTR\ (L_C) + C_{RP}}{(MMBPF)^2}$$

$$\frac{\partial CI}{\partial MMBPF} = \frac{(1 \text{ hr})\ (\$12.50/\text{hr}) + \$20.00}{(25{,}000 \text{ miles})^2} = \$5.20 \times 10^{-6}/100 \text{ mile}^2$$

For a 20 percent deviation of MMBPF, or 5,000 miles,

$$(5{,}000 \text{ miles})\ (\$5.20 \times 10^{-6}/100 \text{ mile}^2) = \$2.6 \times 10^{-2}/\text{mile}$$

Comparing to the nominal CI of $0.360/100 miles, the variation of CI due to a 20 percent deviation of MMBPF is:

$$\frac{\$0.026/100 \text{ Miles}}{\$0.360/100 \text{ Miles}} \times (100) = 7.2 \text{ percent}$$

2.2.3 Effect of MMBM (Mean-Miles-Before-Maintenance)

Following the same logic used in the previous paragraphs:

$$\frac{\partial CI}{\partial MMBM} = \frac{MTTM\ (L_C) + C_{MP}}{(MMBM)^2}$$

Therefore:

$$\frac{\partial CI}{\partial MMBM} = \frac{(0.5 \text{ hr})\ (\$12.50/\text{hr}) + \$2.00}{(12{,}000 \text{ miles})^2} = \$5.74 \times 10^{-6}/100 \text{ mile}^2$$

For 20 percent deviation of MMBM or 2,400 miles:

$$(2{,}400 \text{ miles})\ (\$5.74 \times 10^{-6}/100 \text{ mile}^2) = \$13.8 \times 10^{-3}/\text{mile}$$

Comparing to the nominal value of CI of \$0.360/100 miles the variation of CI due to 20 percent deviation of MMBM is:

$$\frac{\$0.0138/100\text{ miles}}{\$0.360/100\text{ miles}} \times (100) = 3.8\text{ percent}$$

2.2.4 Effect of Fuel Consumption Change

Following previous logic,

$$\frac{\partial CI}{\partial(\Delta\sigma)} = G_C$$

On the basis of the assumed value of G_C of \$0.35/gallon $\frac{\partial CI}{\partial(\Delta\sigma)}$ = \$0.35/gallon.

It is noted that σ_D and σ_B are measured during emission test runs to determine the fuel consumption loss due to the device installation, $\Delta\sigma = (\sigma_D - \sigma_B)$. Paragraph 6.3.2 reviews the average fuel consumption change due to device installation. One device showed an average fuel mileage loss of 10 percent (Table 6-9). In this sample case it will be assumed that the fuel change will be 10 percent instead of 20 percent as in the previous examples. For an average mileage of 15 miles per gallon or 6.67×10^{-2} gallon per mile, a 10 percent increase in fuel consumption is 6.67×10^{-3} gallons/mile. Therefore:

$$(\Delta\sigma)\ (G_C) = (6.67 \times 10^{-3}\text{ gal/mile})\ (\$0.35/\text{gal}) = \$0.223/100\text{ miles}$$

Comparing this with the nominal CI of \$0.360/100 miles the variation of CI due to 10 percent fuel consumption deviation of σ_D is:

$$\frac{\$0.223/100\text{ miles}}{\$0.360/100\text{ miles}} \times (100) = 62\text{ percent}$$

This would be the sensitivity of the fuel consumption increase due to the installation of a device.

2.2.5 Effect of Labor Cost

Following previous logic,

$$\frac{\partial CI}{\partial L_C} = \frac{MTTR}{MMBPF} + \frac{MTTM}{MMBM}$$

then:

$$\frac{\partial CI}{\partial L_C} = \frac{1\text{ hr}}{25{,}000\text{ miles}} + \frac{0.5\text{ hr}}{12{,}000\text{ miles}} = 0.0816\text{ hr/100 miles}$$

For a 20 percent deviation of the assumed average labor cost of \$12.50/hr or \$2.50/hr. the labor cost is:

$$(\$2.50/\text{hr})\ (0.0816 \times \text{hr/mile}) = \$0.0204/100 \text{ miles}$$

Comparing with the nominal CI, the variation of CI due to 20 percent deviation of labor cost is:

$$\frac{\$0.0204/100 \text{ miles}}{\$0.360/100 \text{ miles}} \times (100) = 5.7 \text{ percent}$$

APPENDIX K

COST INDEX RESULTS FOR DEVICES EVALUATED IN RETROFIT PROGRAM

DEVICE No.	DESCRIPTION	INITIAL COST TO CAR OWNER ($)(1)	RECURRING COST TO CAR OWNER ($/100 MI)(4)	COST INDEX ($/100 MI)
	GROUP 1 EXHAUST EMISSION CONTROL SYSTEMS			
	Type 1.1 Exhaust Gas Control Systems:			
	1.1.1 Catalytic Converter			
62	Catalytic Converter	(3)	(3)	(3)
93	Catalytic Converter with Exhaust Gas Recirculation, Spark Modification, and Lean Idle Mixture	(3)	(3)	(3)
96	Catalytic Converter with Distributor Vacuum Advance Disconnect	175(5)	0.171(2)	0.521
292	Catalytic Converter	73	0.047	0.192
	1.1.2 Thermal Reactor			
31	Thermal Reaction by Turbine Blower Air Injection	143	0.051	0.337
244	Rich Thermal Reactor	375(5)	0.036	0.536
463	Rich Thermal Reactor with Exhaust Gas Recirculation and Spark Retard	(3)	(3)	(3)
468	Lean Thermal Reactor with Exhaust Gas Recirculation	(3)	(3)	(3)
	1.1.3 Exhaust Gas Afterburner			
308	Exhaust Gas Afterburner	71	0.108	0.250
425	Exhaust Gas Afterburner	159	0.059	0.377
	1.1.4 Exhaust Gas Filter			
164	Exhaust Gas Filter	103	0.025	0.205
	1.1.5 Exhaust Gas Backpressure			
322	Exhaust Gas Backpressure Valve	(3)	(3)	(3)
	Type 1.2 Induction Control Systems:			
	1.2.1 Air Bleed to Intake Manifold			
1	Air Bleed to Intake Manifold	64	0.022(2)	0.063
42	Air Bleed to Intake Manifold	23	-0.191(2)(6)	-0.161(6)
57	Air Bleed with Exhaust Gas Recirculation and Vacuum Advance Disconnect	63	0.062	0.188
325	Air-Vapor Bleed to Intake Manifold	56	0.342	0.454
401	Air-Vapor Bleed to Intake Manifold	46	0.350	0.442
418	Air Bleed to Intake Manifold	(3)	(3)	(3)
433	Air-Vapor Bleed to Intake Manifold	56	0.342	0.454
458	Air Bleed to Intake Manifold	(3)	(3)	(3)
462	Air Bleed to Intake and Exhaust Manifold	(3)	(3)	(3)
	1.2.2 Exhaust Gas Recirculation			
10	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	71	0.062(2)	0.204
245	Variable Camshaft Timing	78	0.259(2)	0.364
246	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect	89	-0.040(2)(6)	0.079
294	Exhaust Gas Recirculation with Carburetor Modification	(3)	(3)	(3)
	1.2.3 Intake Manifold Modification			
172	Intake Manifold Modification	79	0.0	0.105
384	Air-Fuel Mixture Diffuser	(3)	(3)	(3)
430	Induction Modification	19	0.004	0.030
440	Air-Fuel Mixture Deflection Plate	12	0.004	0.020
	1.2.4 Carburetor Modification			
33	Carburetor Modification, Main Jet Differential Pressure	21	-0.257(2)(6)	-0.229(6)
56	Crankcase Blowby and Idle Air Bleed Modification	54	0.048	0.120
288	Carburetor Main Discharge Nozzle Modification	41	0.144(2)	0.198
295	Carburetor with Variable Venturi	79	0.430(2)	0.536
317	Carburetor Modification with Vacuum Advance Disconnect	23	0.021	0.052
	1.2.5 Turbocharger			
100	Turbocharger	(3)	(3)	(3)

APPENDIX K

COST INDEX RESULTS FOR DEVICES EVALUATED IN RETROFIT PROGRAM (CONCL)

DEVICE NO.	DESCRIPTION	INITIAL COST TO CAR OWNER ($)(1)	RECURRING COST TO CAR OWNER ($/100 MI)(4)	COST INDEX ($/100 MI)
	GROUP 1 EXHAUST EMISSION CONTROL SYSTEMS (Cont)			
	1.2.6 Fuel Injection			
22	Electronic Fuel Injection	(3)	(3)	(3)
	Type 1.3 Ignition Control Systems			
	1.3.1 Ignition Timing Modification			
69	Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification	63	0.069(2)	0.152
175	Ignition Timing Modification with Lean Idle Adjustment	45	0.332(2)	0.391
	1.3.2 Ignition Spark Modification			
23	Electronic Ignition Unit	(3)	(3)	(3)
95	Ignition Spark Modification	(3)	(3)	(3)
259	Photocell-Controlled Ignition System	59	0.025	0.104
268	Capacitive Discharge Ignition	69	0.0	0.046
296	Ignition Timing and Spark Modification	23	0.0	0.031
	Type 1.4 Fuel Modification			
	1.4.1 Alternative Gas Conversion			
52	LPG Conversion	608	0.021	0.224
459	LPG Conversion with Deceleration Unit	608	0.021	0.224
460	Compressed Natural Gas Dual-Fuel Conversion	601	(3)	(3)
461	LPG Conversion with Exhaust Reactor Pulse Air Injection and Exhaust Gas Recirculation	(3)	(3)	(3)
464	Methanol Fuel Conversion with Catalytic Converter	(3)	(3)	(3)
466	LPG-Gasoline Dual-Fuel Conversion	(3)	(3)	(3)
	1.4.2 Fuel Additive			
182	Fuel and Oil Additives	1/	0.293	(3)
282	LP Gas Injection	118	0.073	0.309
457	Water Injection	(3)	(3)	(3)
465	Fuel Additive	(3)	(3)	(3)
	1.4.3 Fuel Conditioner			
36	Fuel Conditioning by Exposure to Electromagnetic Field	(3)	(3)	(3)
279	Fuel Conditioner	16	0.0	0.033
	GROUP 2 CRANKCASE EMISSION CONTROL SYSTEMS			
	Type 2.1 Closed Systems			
24	Heavy Duty Positive Crankcase Control Valve with Air Bleed	34	0.013	0.047
170	Closed Blowby Control System	39	0.026	0.065
315	Closed Blowby Control System	69	0.038	0.175
427	Closed or Open Blowby Control System with Filter	68	0.135	0.271
	Type 2.2 Open Systems			
160	Closed or Open Blowby Control System with Filter	69	0.051	0.143
	GROUP 3 EVAPORATIVE EMISSION CONTROL SYSTEMS			
467	Fuel Evaporation Control System	137	(3)	(3)
	GROUP 4 EMISSION CONTROL COMBINATIONS			
59	Three-Stage Exhaust Gas Control System	(3)	(3)	(3)
165	Exhaust Gas Afterburner/Recirculation with Blowby and and Fuel Evaporation Recirculation	238	0.073	0.549
408	Exhaust Gas and Blowby Recirculation with Intake Vacuum Control and Turbulent Mixing	36	0.067	0.139
469	Rich Thermal Reactor with Exhaust Gas Recirculation and Particulate Control	400	(3)	(3)

(1) Estimated retail costs of material and labor excluding engine tuneup costs not related to device installation.
(2) Device tested in retrofit program.
(3) Insufficient data on which to base cost estimate.
(4) Recurring costs include fuel consumption change as measured during 1972 Federal Test Procedure for emissions. Leaded gasoline cost of $0.35/gallon was used for all devices, except Device 96, for which unleaded gasoline cost of $0.38/gallon was used. For devices not tested in retrofit program, recurring costs do not include fuel consumption effects, as fuel data from the retrofit developers were incomplete generally.
(5) For 8-cylinder engine.
(6) Negative values represent cost savings due to increased miles per gallon of fuel.

APPENDIX L

FUEL CONSUMPTION MEASURED DURING THE 1972 FEDERAL TEST FOR DEVICES TESTED IN THE RETROFIT PROGRAM

DEVICE NO. AND LOCATION	CAR NO.	MAKE AND CID	FUEL CONSUMPTION (MILES/GALLON)		
			BASELINE	RETROFIT	PERCENT CHANGE (1)
AIR BLEED TO INTAKE MANIFOLD					
1:	1	65 Chev 194	14.8	11.4	-23
(Anaheim)	2	65 Ford 289	13.7	13.7	0
	3	65 Ply 318	10.3	(3)	(3)
	4	65 Chev 327	15.4	13.2	-14
	5	65 Ford 390	11.0	13.2	20
	6	61 Chev 283	12.5	14.8	18
	19	65 VW 92	20.0	(3)	(3)
AIR BLEED TO INTAKE MANIFOLD					
1:	8	65 Ford 289	11.6	13.7	18
(Taylor)	8R(4)		12.6	(3)	(3)
	9	65 Ply 318	13.0	(3)	(3)
	9R		13.5	16.1	19
	10	65 Chev 327	12.3	15.4	25
	10R		14.2	14.2	0
	11	65 Ford 390	13.0	14.5	12
	11R		10.7	13.7	28
	12	61 Chev 283	15.4	15.7	2
	12R		17.3	13.0	-24
	20	65 VW 92	21.2	15.1	-29
			Device 1 Average Change		4
CATALYTIC CONVERTER WITH DISTRIBUTOR VACUUM ADVANCE DISCONNECT					
96:	1(2)	65 Chev 194	12.3	15.7	28
(Anaheim)	1R(2)		15.7	13.2	-16
	2(2)	65 Ford 289	11.6	13.7	18
	2R(2)		12.3	11.0	-11
	3	65 Ply 318	14.2	13.2	-7
	3R(2)		11.7	11.4	-3
	4(2)	65 Chev 327	14.2	11.7	-18
	4R(2)		14.5	13.7	-6
	5	65 Ford 390	12.1	11.7	-3
	5R		11.4	10.4	-9
	6(2)	61 Chev 283	13.5	11.2	-17
	6R		13.5	10.7	-20
CATALYTIC CONVERTER WITH DISTRIBUTOR VACUUM ADVANCE DISCONNECT					
96:	8	65 Ford 289	(3)	13.5	(3)
(Taylor)	9	65 Ply 318	13.0	14.2	9
	10	65 Chev 327	10.0	13.2	32
	11(2)	65 Ford 390	14.0	15.4	10
	12(2)	61 Chev 283	14.5	14.0	-3
			Device 96 Average Change		-1
IGNITION TIMING MODIFICATION WITH LEAN IDLE ADJUSTMENT					
175:	1	65 Chev 194	(3)	14.8	(3)
(Anaheim)	2	65 Ford 289	Car Not Tested		
	3	65 Ply 318	11.6	9.9	-15
	4	65 Chev 327	14.2	13.7	-4
	5	65 Ford 390	11.6	9.7	-16
	6	61 Chev 283	(3)	(3)	(3)
IGNITION TIMING MODIFICATION WITH LEAN IDLE ADJUSTMENT					
175:	8	65 Ford 289	14.0	13.2	-6
(Taylor)	9	65 Ply 318	12.6	13.2	5
	10	65 Chev 327	14.2	11.6	-18
	11	65 Ford 390	12.1	13.0	7
	12	61 Chev 283	13.2	10.6	-20
	16	65 Chev 327	16.1	12.0	-26
			Device 175 Average Change		-10

APPENDIX L

FUEL CONSUMPTION MEASURED DURING THE 1972 FEDERAL TEST FOR DEVICES TESTED IN THE RETROFIT PROGRAM (CONCL)

DEVICE NO. AND LOCATION	CAR NO.	MAKE AND CID	FUEL CONSUMPTION (MILES/GALLON)		
			BASELINE	RETROFIT	PERCENT CHANGE (1)
SPEED-CONTROLLED EXHAUST GAS RECIRCULATION WITH VACUUM ADVANCE DISCONNECT					
246: (Anaheim)	1	65 Chev 194	(3)	11.6	(3)
	2	65 Ford 289	14.2	11.4	-20
	3	65 Ply 318	10.0	12.8	28
	4	65 Chev 327	12.8	11.9	-7
	17	65 Ford 390	9.4	10.6	13
	18	61 Chev 283	10.5	11.6	11
	19	65 VW 92	(3)	(3)	(3)
SPEED-CONTROLLED EXHAUST GAS RECIRCULATION WITH VACUUM ADVANCE DISCONNECT					
246: (Taylor)	8	65 Ford 298	(3)	(3)	(3)
	8R		12.8	14.5	13
	9	65 Ply 318	12.7	14.0	10
	9R		13.5	(3)	(3)
	10	65 Chev 327	(3)	(3)	(3)
	10R		(3)	14.0	(3)
	11	65 Ford 390	12.3	13.0	6
	11R		11.6	15.8	36
	12	61 Chev 283	14.8	14.2	-4
	12R		16.5	14.5	-12
	20(3)	65 VW 92	(3)	(3)	(3)
			Device 246 Average Change		7
THROTTLE-CONTROLLED EXHAUST GAS RECIRCULATION WITH VACUUM ADVANCE DISCONNECT					
10: (Anaheim)	4	65 Chev 327	13.2	13.7	4
	6	65 Ford 390	12.5	12.1	-3
CARBURETOR MODIFICATION MAIN JET DIFFERENTIAL PRESSURE					
33: (Anaheim)	2	65 Ford 289	11.4	15.4	35
	4	65 Chev 327	14.2	12.8	-10
AIR BLEED TO INTAKE MANIFOLD					
42: (Anaheim)	4	65 Chev 327	13.7	13.7	0
	5	65 Ford 390	10.4	11.9	14
ELECTRONIC-CONTROLLED VACUUM ADVANCE DISCONNECT AND CARBURETOR LEAN IDLE MODIFICATION					
69: (Anaheim)	3	65 Ply 318	13.0	11.9	-8
	4	65 Chev 327	13.2	11.4	-14
	5	65 Ford 390	10.9	13.2	21
VARIABLE CAMSHAFT TIMING					
245: (Anaheim)	6	61 Chev 283	16.8	15.1	-10
CARBURETOR MAIN DISCHARGE NOZZLE MODIFICATION					
288: (Anaheim)	2	65 Ford 289	14.5	14.5	0
	6	61 Chev 283	16.8	14.8	-12
CARBURETOR WITH VARIABLE VENTURI					
295 (Anaheim)	5	65 Ford 390	11.0	9.9	-10

(1) Negative values indicate worse mileage.
(2) Air pump installed.
(3) Test data invalid.
(4) "R" designates replicate test.
(5) Olson Laboratories, Inc., emission and driveability test facilities at Anaheim, California, and Taylor, Michigan, were used in the retrofit study test program.